NASA/SP-2009-

United States Human Access to Space, Exploration of the Moon and Preparation for Mars Exploration

A White Paper on the Progress of the NASA Constellation Program

February 2009

Prepared by the Staff of the Constellation Program

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CONSTELLATION

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Acronyms

AMNH	American Museum of Natural History
CAIB	Columbia Accident Investigation Board
CaLV	Cargo Crew Launch Vehicle
CEV	Crew Exploration Vehicle
CLV	Crew Launch Vehicle
COTS	Commercial Orbital Transportation Services
CxAT Lunar	Constellation Lunar Architecture Team
DRM	Design Reference Mission
EDL	Exploration Development Laboratory
EDS	Earth Departure Stage
ESAS	Exploration Systems Architecture Study
ESMD	Exploration Systems Mission Directorate
ET	External Tank
EVA	Extravehicular Activity
FOC	Full Operational Capability
IET	Integrated Environment Testing
IPP	Innovative Partners Program
ISS	International Space Station
ITEA	International Technology Education Association
LAS	Launch Escape System
LCCR	Lunar Capability Concept Review
PA-1	Pad Abort-1
RFSA	Russian Federal Space Agency
SRBs	Solid Rocket Boosters
STEM	Science, Technology, Engineering and Mathematics
VAB	Vehicle Assembly Building

1.0 Executive Summary

1.1 Introduction

In the past, men like Leonardo da Vinci and Jules Verne imagined the future and envisioned fantastic inventions such as winged flying machines, submarines, and parachutes, and posited human adventures like transoceanic flight and journeys to the Moon. Today, many of their ideas are reality and form the basis for our modern world.

While individual visionaries like da Vinci and Verne are remembered for the accuracy of their predictions, today entire nations are involved in the process of envisioning and defining the future development of mankind, both on and beyond the Earth itself. Recently, Russian, European, and Chinese teams have all announced plans for developing their own next generation human space vehicles. The Chinese have announced their intention to conduct human lunar exploration, and have flown three crewed space missions since 2003, including a flight with three crew members to test their extravehicular (spacewalking) capabilities in September 2008. Very soon, the prestige, economic development, scientific discovery, and strategic security advantage historically associated with leadership in space exploration and exploitation may no longer be the undisputed province of the United States.

Much like the sponsors of the seafaring explorers of da Vinci's age, we are motivated by the opportunity to obtain new knowledge and new resources for the growth and development of our own civilization. NASA's new Constellation Program, established in 2005, is tasked with maintaining the United States leadership in space, exploring the Moon, creating a sustained human lunar presence, and eventually extending human operations to Mars and beyond.

Through 2008, the Constellation Program developed a full set of detailed program requirements and is now completing the preliminary design phase for the new Orion Crew Exploration Vehicle (CEV), the Ares I Crew Launch Vehicle, and the associated infrastructure necessary for humans to explore the Moon. Component testing is well underway, and integrated flight testing will begin in 2009. This white paper summarizes 3 years of Constellation Program progress and accomplishments, and it describes the foundation set for human lunar return in 2020.

1.2 A Brief History of U.S. Human Space Exploration

In the late 1950s, the U.S. embarked upon the ongoing campaign of human space exploration. The first human spaceflight initiative was Project Mercury, followed by Project Gemini and the Apollo Program. Project Mercury was established in October 1958 with single-pilot spacecraft first launched from Cape Canaveral Air Force Station in the early 1960s. Project Gemini was announced in January 1962 and served to perfect spacecraft maneuvers and multi-crew operations in Earth orbit. The Apollo Program was initiated in 1961, successfully allowing humans to travel beyond Earth orbit for the first time and to explore the surface of the Moon with six teams of astronaut/scientists between 1969 and 1972. Apollo hardware was also adapted for use in the Skylab and Apollo-Soyuz projects.

In the mid-1970s, NASA began development of the Space Transportation System (commonly known as the Space Shuttle) as the next crewed vehicle. Over the past 27 years, the Space Shuttle fleet has supported more than 100 research and technology missions and 27 missions, to date, in the construction and operation of the International Space Station (ISS).

Planning for the ISS Program began in the late 1980s. Building on NASA's experience with the Skylab Program of the 1970s, and incorporating the Russian experience with Salyut and Mir space stations, the first components of the ISS were placed into orbit in 1998. Over the past 10 years, the United States, Japan, Canada, Russia, and 11 countries represented by the European Space Agency have worked together to construct the ISS and use the growing laboratory as a base for increasingly complex science research and technology development. As the assembly of the ISS nears its scheduled completion in 2010, ambitious plans are being developed for larger rotational crews and full use of its capabilities as an international research facility in orbit. The international partnership of space agencies involved in ISS research met in July 2008, to assess the progress and potential of the space station and agreed that there were no technical challenges to extending ISS operation beyond 2015.[1]

1.3 Our New Exploration Initiative

Following the Space Shuttle *Columbia* accident on February 1, 2003, NASA established the Columbia Accident Investigation Board (CAIB) to perform an in-depth review of the Space Shuttle Program. In their report, the CAIB concluded that it was in the best interest of the U.S. to develop a replacement for the Space Shuttle.[2]

In January 2004, President George W. Bush announced a new exploration initiative (the *Vision for Space Exploration*) to return humans to the Moon by 2020 in preparation for human exploration of Mars and beyond.[3] As part of this initiative, NASA was directed to continue to use the Space Shuttle fleet to fulfill its obligation to complete assembly of the ISS and then retire the fleet by 2010. As the first step toward developing the vehicles to explore the Moon, Mars, and beyond, the President directed NASA to build and fly a new Crew Exploration Vehicle (CEV). Named Orion in 2006, the spacecraft will be a new multi-function human-rated space vehicle capable of transporting six crew members to the ISS and carrying crews and equipment to and from lunar orbit.

As originally envisioned, the U.S. would rely on the Russian Soyuz rocket and space capsule to ferry American crew members to the ISS during the period between Space Shuttle retirement in 2010 and the new Orion CEV operational launch capability in 2014. The Soyuz is launched from the Baikonur spaceport in central Kazakhstan and funded through a direct contract with the Russian Federal Space Agency (RFSA). In April 2007, NASA announced a $719 million modification to the current contract with the RFSA "for crew and cargo services through 2011."[4] Due to NASA budget constraints, the Full Operational Capability (FOC) date for the CEV has moved from 2014 to late 2015. Since the Russian space agency requires a 3-year lead time to manufacture the Soyuz hardware, a decision to purchase additional services beyond 2011 was required by the end of 2008. In late September 2008, the U.S. House of Representatives extended the waiver to the Iran-North Korea-Syria Nonproliferation Act, which will allow NASA to continue to purchase Soyuz hardware and services until 2016. This bill was passed by the House and Senate and signed by the President on September 30. 2008. Counter arguments for continuing to fly the Space Shuttle and for increasing funding to the Orion and Ares projects to accelerate development and FOC, rather than extend the Soyuz contract, are also being considered.[5] This potential gap in launch capability is described in more detail in Appendix A of this paper.

Congress has expressly endorsed the President's exploration initiative with authorization legislation and provided additional direction for the initiative in the NASA Authorization Act of 2005, authorizing NASA to "…establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations."

1.4 The Exploration Systems Architecture Study[6]

In May 2005, in response to the President's exploration initiative, NASA Administrator Michael Griffin commissioned the Exploration Systems Architecture Study (ESAS) to perform four specific tasks:

1. Complete assessment of the top-level Orion CEV requirements and plans to enable the vehicle to provide crew transport to the ISS and to accelerate the development of the Orion CEV and crew launch system to reduce the gap between Space Shuttle retirement and CEV initial operational capability.
2. Provide definition of top-level requirements and configurations for crew and cargo launch systems to support the lunar and Mars exploration programs.
3. Develop a reference lunar exploration architecture concept to support sustained human and robotic lunar exploration operations.
4. Identify key technologies required to enable and significantly enhance these reference exploration systems and reprioritize near- and far-term technology investments.

The ESAS Team was comprised of representatives from all NASA centers, private industry consultants, and retired NASA personnel. The team also included an independent review team with members from the Congressional Review Service, George Washington University, the United States Air Force, the University of Arizona, and the Naval Research Laboratory.

The ESAS Team took on the task of developing Orion CEV requirements and a baseline configuration to meet those requirements. Many design studies were performed to address potential CEV shapes, including blunt-body, slender-body, and lifting shapes. Aspects of an Orion CEV mission to the ISS were examined in detail, including docking approaches and the use of the CEV as a cargo transport and return vehicle.

The ESAS Team studied multiple combinations of launch elements to perform missions to the ISS, the Moon, and Mars. Different types and sizes of launch vehicles and numbers of launches required to meet specific mission configurations called Design Reference Missions (DRMs) were evaluated. The ESAS Team performed a detailed examination of the costs, schedule, reliability, safety, and risk of using launch vehicles derived from the Space Shuttle and from current and proposed U.S. heavy-lift launch vehicles (e.g., Delta IV and Atlas V launch vehicles) for crew and cargo missions. Other studies included propellant types for launch vehicle stages, numbers of engines per stage, use of common components and systems on vehicle stages, and number of stages.

To determine the crew and cargo transportation requirements, the ESAS Team examined a variety of lunar surface mission types, surface systems, and approaches to constructing a lunar outpost. These assessments of the exploration goals and mission requirements were formulated into the ESAS as a set of recommendations for a future exploration architecture. The study concluded that the launch vehicles should be derived from existing technologies, leveraging the lessons learned from past programs, such as the Apollo Program and the Space Shuttle Program. Specifically, the ESAS recommended an architecture that included a Crew Launch Vehicle (CLV [since named Ares I]) to ferry crew and cargo to the ISS and to carry crew to Earth orbit and a heavy-lift Cargo Launch Vehicle (CaLV [since named Ares V]) to support missions to the Moon and Mars.

1.5 The Constellation Program

NASA established the Constellation Program in 2005 to plan, develop, test, integrate, and operate all of the elements necessary to comply with Presidential and Congressional directives regarding the new exploration initiative. The Constellation Program used those directives and the ESAS Team's recommendations as a starting point and has refined the mission requirements, evaluated capabilities for the technologies studied by the ESAS, and performed a more detailed examination of the developmental requirements (e.g., test and verification requirements). As the long-term objectives of U.S. space exploration continue to evolve, the near-term goals are well-established and underway: develop the flight systems and ground infrastructure required to enable continued access to space and enable future crewed missions to the ISS, Moon, and Mars.

The Orion CEV and two new launch vehicles, the Ares I and Ares V, are in development to meet these goals. The Orion CEV will be carried atop the Ares I to low Earth orbit where it will dock with either the ISS or with a payload launched earlier on an Ares V launch vehicle for transit to the Moon. For lunar missions, the Ares V launch vehicle will carry an Earth Departure Stage and a Lunar Payload (e.g., a lander) in a single launch. After the Orion CEV docks with the Earth Departure Stage/Lunar Payload in Earth orbit, the Earth Departure Stage engine will ignite and propel the Lunar Payload and the Orion CEV to the Moon. For future missions to Mars, Ares V launch vehicles would be used to launch the components needed to send and return a crew to Mars. This could include a Mars transfer vehicle, a lander, a surface habitat, and surface equipment. The Ares I and Orion CEV will also be used for crew transport to and from low Earth orbit for the Mars missions.

The primary components of this campaign architecture and an exploration timeline are shown in figure 1-1.

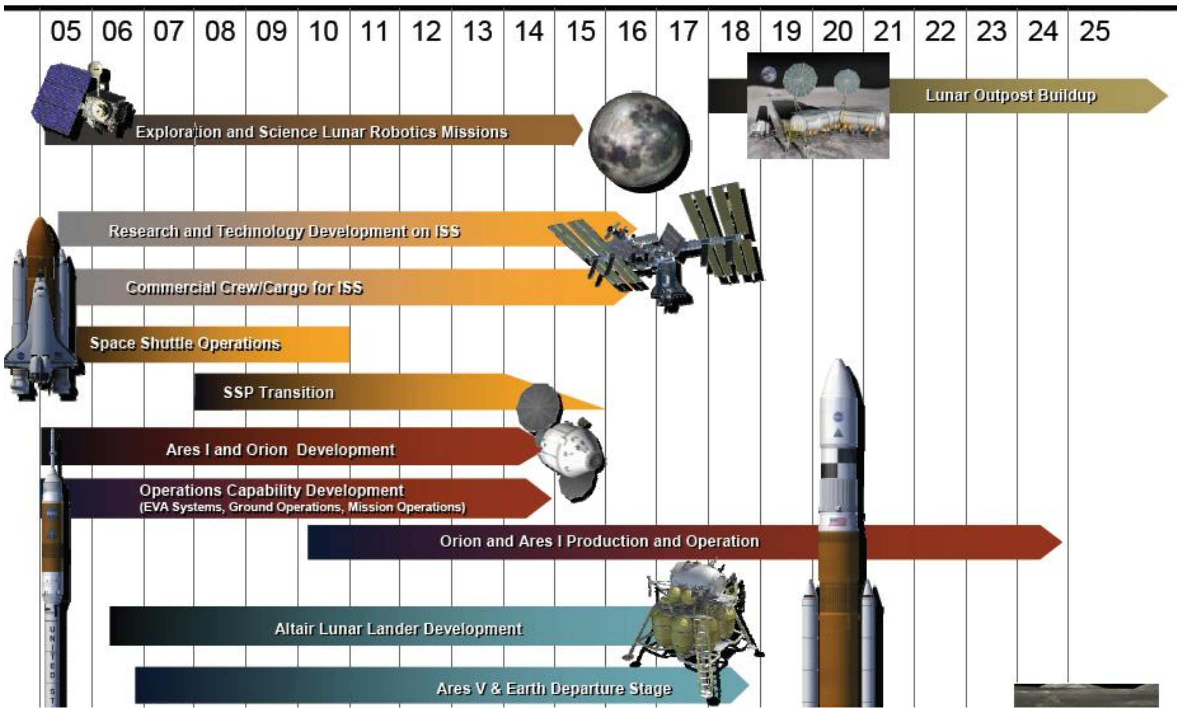


Figure 1-1. The overall U.S. Human Space Exploration roadmap.

In support of this exploration plan, the Constellation Program manages the following seven "hardware development" project offices:

- Crew Exploration Vehicle Project (the Orion spacecraft) at Johnson Space Center in Houston, Texas
- Ares Project (the Ares I and Ares V launch vehicles) at Marshall Space Flight Center in Huntsville, Alabama
- Ground Operations Project (development of ground processing, launch and recovery facilities) at Kennedy Space Center in Florida
- Mission Operations Project (development of flight and mission control facilities) at Johnson Space Center in Houston, Texas
- Extravehicular Activity (EVA) Systems Project (spacesuit and tool development) at Johnson Space Center in Houston, Texas
- Altair Project (the lunar descent and ascent module) at Johnson Space Center in Houston, Texas
- Lunar Surface Systems Project (advanced planning for lunar habitats and surface support systems) at Johnson Space Center in Houston, Texas.

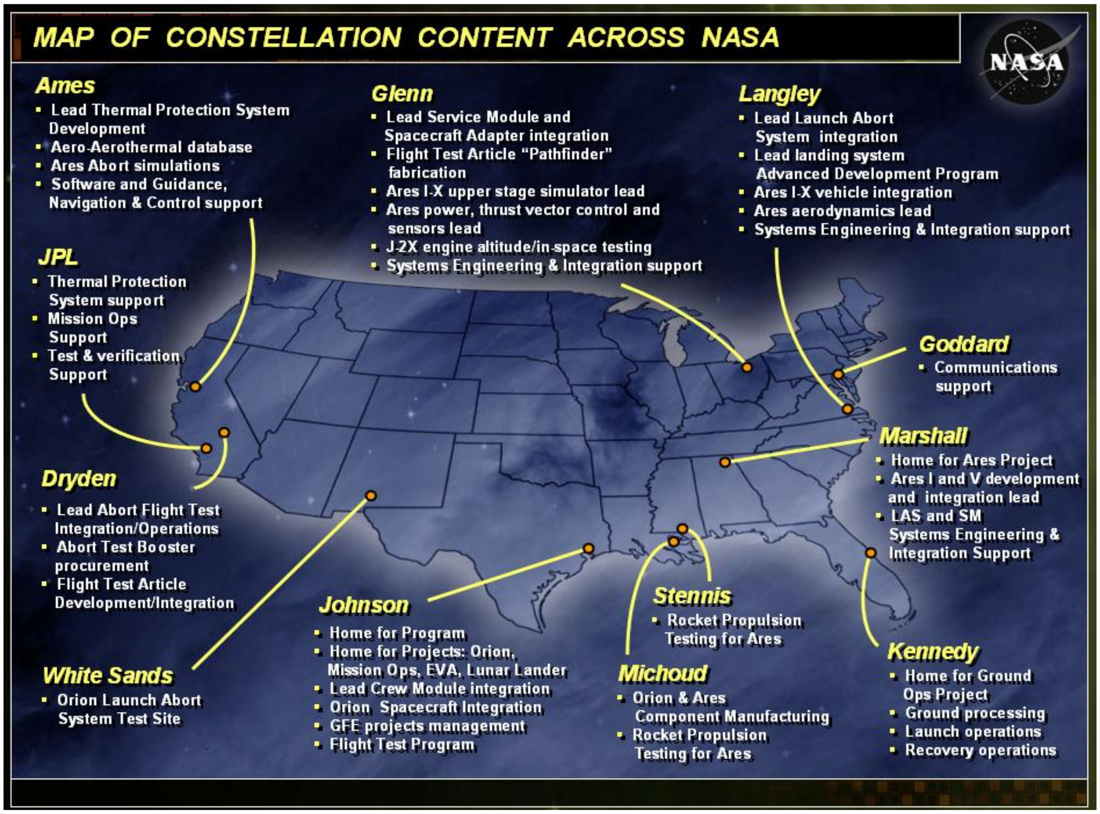
In addition to these project offices, work assignments for specific Constellation hardware development and testing involve major NASA facilities in California, Louisiana, Maryland, Mississippi, New Mexico, Ohio, and Virginia. A geographic summary of NASA and contractor work distribution is shown in figure 1-2.

The current program schedule (with major milestones established by Presidential and Congressional direction) calls for the transport of humans to and from the ISS by 2015 (FOC for the program), and the transport of humans to and from the Moon by 2020. As directed by the President, retirement of the Space Shuttle fleet is expected to occur by 2010 and is a separate program activity within NASA.

The initial target date for the first operational crewed ISS flight was 2014; however, the Constellation Program was allocated less funding than planned in the annual 2007 Federal appropriation bill. Since a primary rule adopted by this program is a "go as you can afford to pay" philosophy, this funding shortfall resulted in a 6-month operational delay that postponed the ISS launch and FOC from 2014 to 2015.

As currently envisioned, an incremental buildup to lunar exploration would begin with four-person crews making several short-duration trips of up to 14 days to the Moon until power supplies, rovers, and living quarters become operational. These initial missions would focus on building a lunar outpost, followed by long-duration lunar missions, increasing up to 180 days. The goal of these efforts is to establish a sustained human presence on the Moon as part of an international scientific research effort similar to the current ISS human presence in low Earth orbit and polar research activities conducted on Earth.

In addition to basic science and research activities, lunar exploration will allow the United States to develop and test the necessary engineering, technology, social and legal infrastructure that will support the beginning of human exploration of our solar system, most notably of Mars, the Martian moons, the gravitationally stable Lagrange points in the Earth-Moon-Sun system, and a variety of Earth-approaching asteroids and comets. Another important aspect of sustained lunar activity will be the opportunity to engage the international community in a long-term, high-visibility program of cooperation and mutual benefit following the success of the ISS.



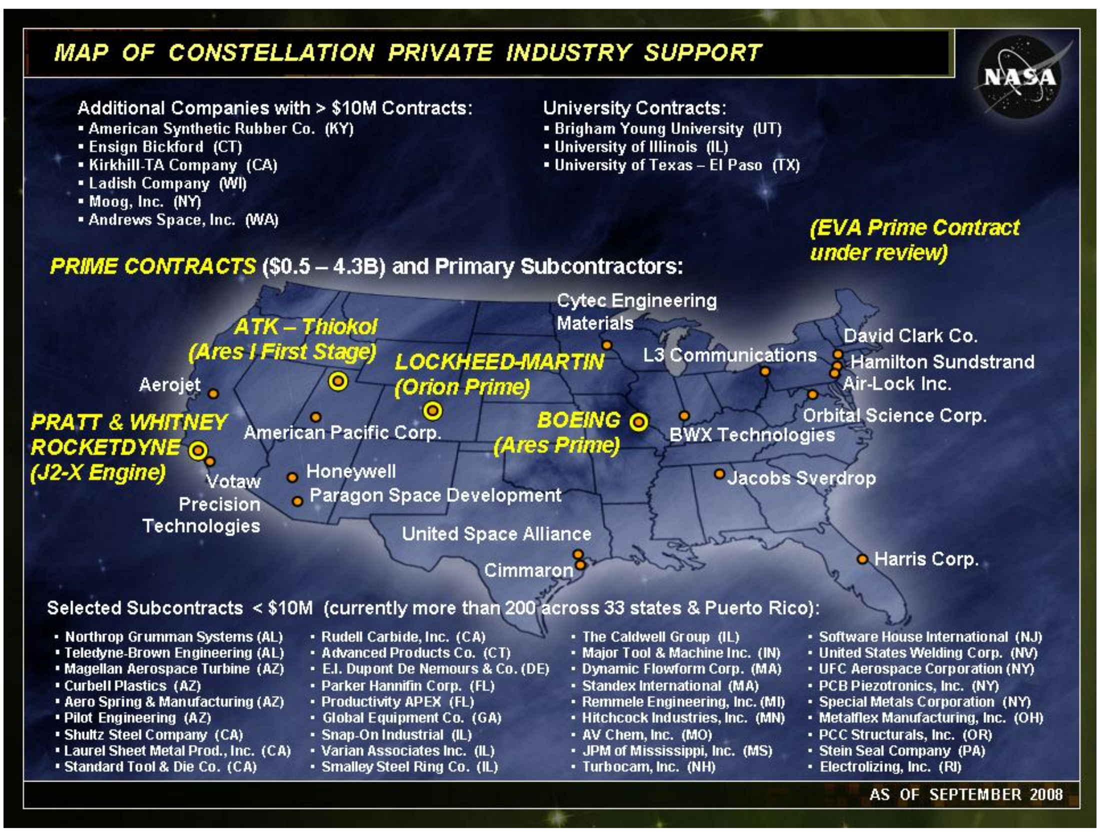


Figure 1-2. Constellation work by NASA center (above) and by contractor companies (below).

In May 2007, NASA developed a Global Exploration Strategy with a number of space agencies from around the world (Italy, United Kingdom, France, China, Canada, Australia, Germany, the European Space Agency, India, Japan, Republic of Korea, Ukraine, and Russia). The Global Exploration Strategy framework document[7] proposes the formation of a voluntary, non-binding coordination group through which individual agencies may exchange information regarding interests, objectives, and plans in space exploration with the goal of strengthening both individual exploration programs as well as the collective effort. This coordination group, now called the International Space Exploration Coordination Group, has agreed upon five broad Global Exploration Strategy themes which can serve as the basis for future global cooperation in space:

- New knowledge in science and technology – a global, science-driven methodology to generate new discoveries and produce new tools which will enhance the quality of life for all people on Earth.

- A sustained human presence in space – extending human frontiers and acknowledging our common human need for exploration and expansion.

- Economic expansion – laying the groundwork for commercial activities in and supporting space exploration and promoting participation by the private (non-government) sector, resulting in the creation of new industries, new jobs, and increased financial returns for both private and government participants (profits and taxes).

- Global partnership – no single nation has the resources to fully explore and exploit the space environment, and all nations will benefit from cooperation through sharing of information and elimination of expensive duplication of effort. Establishing a strong international tradition of cooperation and interdependence in the early phase of global space exploration will help ensure that these activities remain peaceful, financially efficient, and beneficial for all of humanity.

- Inspiration and education – space exploration captures the human attention and imagination in a special way. The concept and allure of space exploration is common to all people, evident in stories from our earliest civilizations and in our latest films and novels, and is a powerful motivating force behind advances in real-life science and technology. Space exploration can provide unique educational inspiration and employment opportunities for young people around the world.

While the majority of current activities within the Constellation Program are focused on executing the human space exploration roadmap, significant efforts are underway regarding commercialization, education, and public outreach aspects of our space exploration policy. These efforts are described in more detail in Appendix B.

1.6 Current Constellation Progress and Activities

By 2007, the Constellation Program had developed detailed program requirements and is now completing the design phase associated with development of the Orion CEV and Ares vehicles, and associated infrastructure necessary for humans to explore the Moon. This formulation phase has included the study of various design options, the definition of system requirements, finalizing conceptual methodologies, and the selection of contractor organizations to help NASA develop and build the new hardware and software.[8]

By the end of 2008, the Constellation projects will have awarded procurements for their required hardware and software, and started developmental component testing on their respective systems. In addition to extensive computer design and simulation work, Orion and Ares have already conducted engine and motor test firings, parachute drop tests, airbag landing tests, thermal protection system tests, and vehicle wind tunnel tests.

Orion is planning to conduct the Pad Abort 1 (PA-1) test flight from the White Sands Missile Range in New Mexico in Spring 2009. The test will verify the design of the Orion launch abort system that allows the crew to escape in the event of a problem on the launch pad or during ascent to orbit after launch. PA-1 will be followed by a series of increasingly complex suborbital flights to test pad and ascent abort systems between 2009 and 2012.

The Ares 1-X launch is scheduled for 2009 from Pad 39-B at Kennedy Space Center and will be the first developmental flight test of the Ares I first stage rocket. This test flight will provide important information to be used in the final design of the Ares I launch vehicle. The test will be a 2-minute suborbital flight and will include mass-simulators for the upper stage and Orion crew vehicle (since both components are still in development at this time). The first stage Ares I rocket is derived from the Space Shuttle solid rocket booster. This will be followed by another uncrewed Ares I-Y test flight in late 2013.

These Orion and Ares test flights are leading up to an uncrewed orbital flight test of the complete vehicle in early 2014 (Orion-1), and the first crewed launch in late 2014 (Orion-2). At this point, the Orion vehicle will begin routine operations of two flights per year to Earth orbit to support the ISS. Based on our current budget, the program is committed to Full Operational Capability with Orion-4 in 2015. A summary schedule of Constellation flight test activity is shown in figure 1-3.

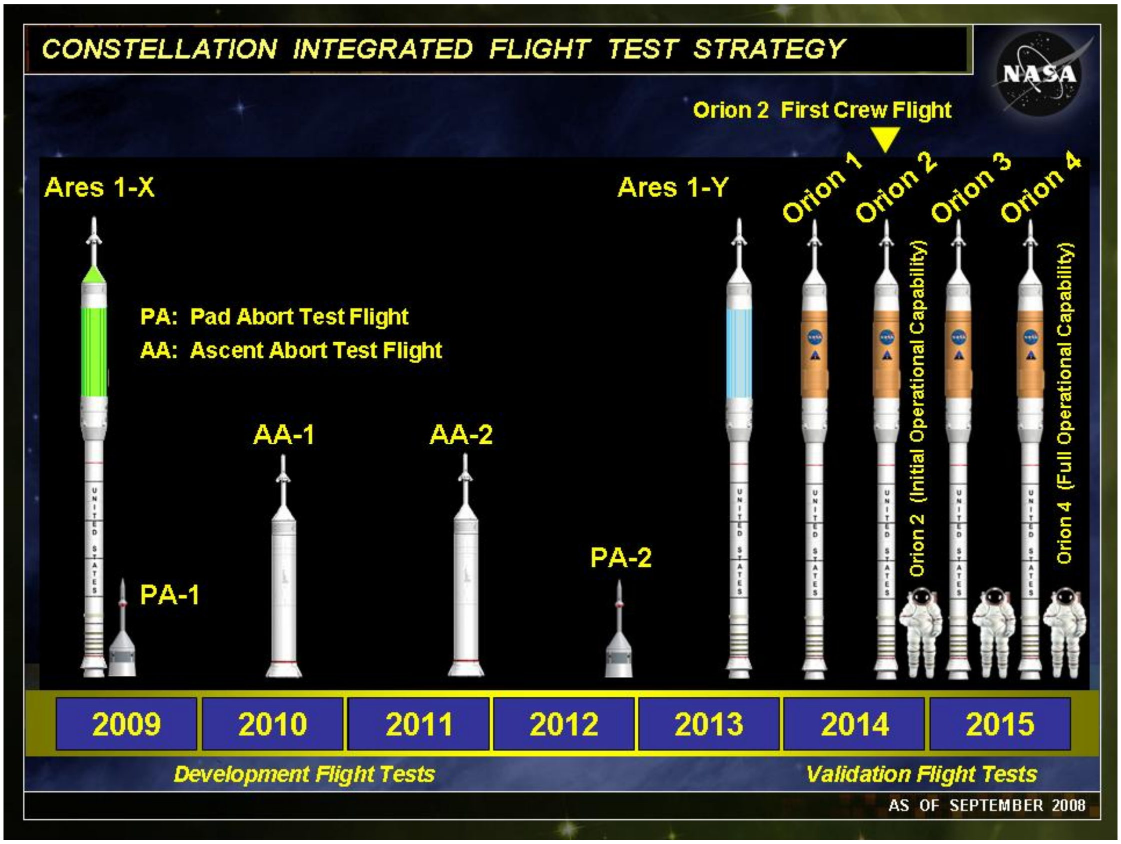


Figure 1-3. Constellation Flight Test Program and the beginning of full operational flights in 2015.

In addition to preparations for the vehicle tests mentioned above, construction of key test, processing, and launch facilities are already well underway in New Mexico, Ohio, Mississippi, Alabama, Virginia, California, Texas, and Florida. Some of these facilities are new, and some are being refurbished from existing Space Shuttle and Apollo-era facilities. These facility projects are described in more detail later in this paper.

The human lunar return flight of the Altair lunar lander and Earth Departure Stage is scheduled for 2020 aboard the heavy-lift Ares V rocket. It is anticipated that a series of test vehicles will be used for flight tests in Earth orbit prior to this milestone (similar to the flight tests of the Apollo Saturn vehicle and lunar module). Altair will be capable of landing four astronauts on the lunar surface, providing life support and a base for the initial week-long surface exploration missions, and returning the crew to the Orion spacecraft in lunar orbit. A follow-on version of the Altair will be an uncrewed autonomous cargo carrier which will deliver outpost elements, rovers, and other scientific equipment to the lunar surface. Figure 1-4 shows the major lunar exploration vehicle elements and a simplified mission profile.

A seventh Constellation Project, the Lunar Surface Systems Project, is in the early stage of formulation. The ESAS team defined a limited framework for lunar surface activities, and their lunar surface work has been continued by the Constellation Lunar Architecture Team (CxAT Lunar). A number of CxAT Lunar studies culminated in a 9-month Lunar Capability Concept Review (LCCR) which was completed in June, 2008.[9] This study investigated possible extended-stay lunar mission scenarios, including the use of lunar resources for the on-site (or in situ) production of power, oxygen, and fuel, and compared them with the capabilities of the emerging Orion, Altair, and Ares designs to provide a basis for the Lunar Surface Systems Project to begin initial hardware and software requirements development. In turn, the Orion, Altair, and Ares projects have begun to incorporate key design requirements from the LCCR into their designs, and are working with the Lunar Surface Systems Project to ensure a compatible program design which will support eventual long-duration stays on the lunar surface.

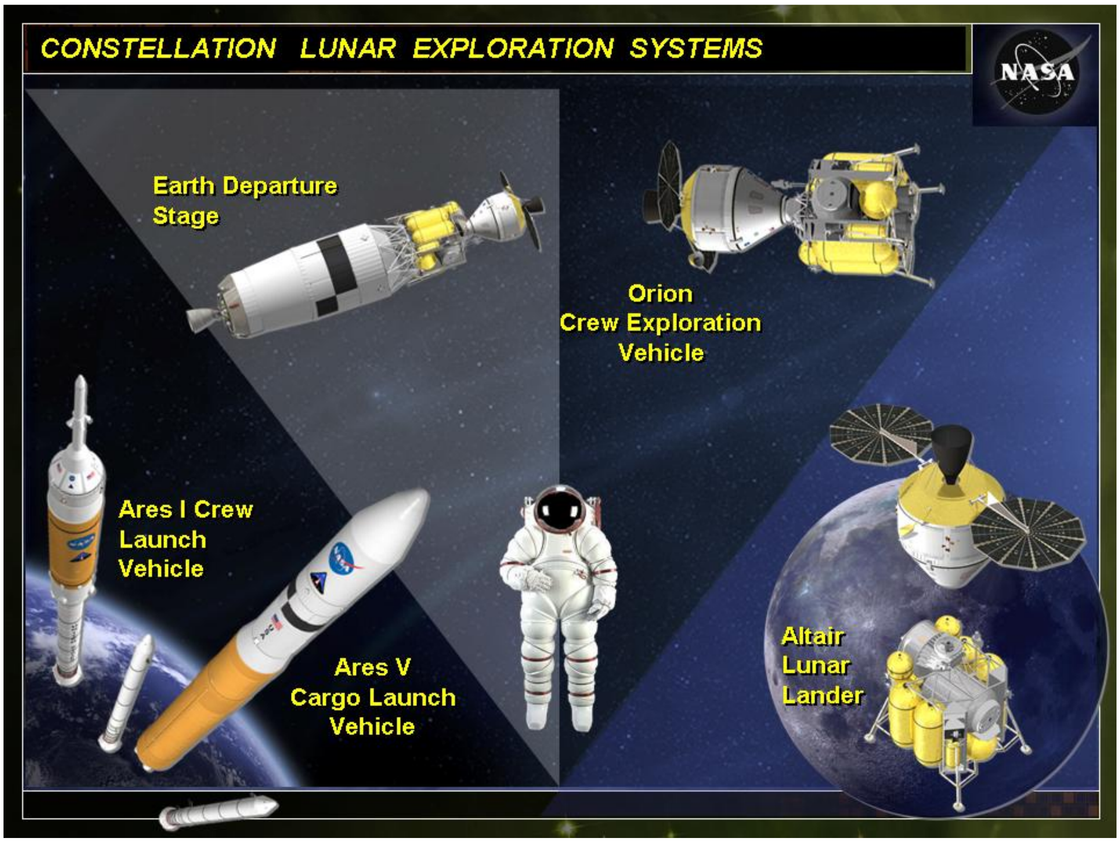


Figure 1-4. Basic Constellation lunar exploration vehicle architecture.

The LCCR established a feasible point-of-departure architecture (not a final baseline) that will be used as a common starting point by the Constellation projects to refine concepts and begin to discuss and define requirements, and eventually hardware, for extended lunar operations. A Lunar Surface Concept Review will be conducted in several years to assess specific proposals and potential international partner contributions for an early lunar outpost.

This type of concurrent short-term and long-term design development between Constellation projects is a key element of efficient systems engineering and will help minimize program cost and risk, while allowing the optimization of performance among all vehicles and key elements in program architecture.

NASA has already begun to construct and test prototype lunar surface hardware in an effort to determine which designs show promise for future development. Figure 1-5 shows a variety of habitat modules, mobility equipment, and planetary surface navigation techniques currently being tested in harsh environments from the Arctic Circle to Antarctica.

Figure 1-5: Prototype inflatable lunar habitats are tested in the Antarctic. Surface suits and a new rover concept vehicle, along with mobile lunar habitats and scout robots, are tested at Moses Lake in Washington. An experimental Humvee rover and all-terrain scout vehicles are used to test planetary surface navigation techniques (a 230-kilometer trek using only satellite imagery and topography data) on the Mars-like polar desert terrain of Devon Island inside the Arctic Circle.

Based on this prototype testing and studies presented at the LCCR, a variety of feasible lunar surface outpost architecture elements are shown in figure 1-6.

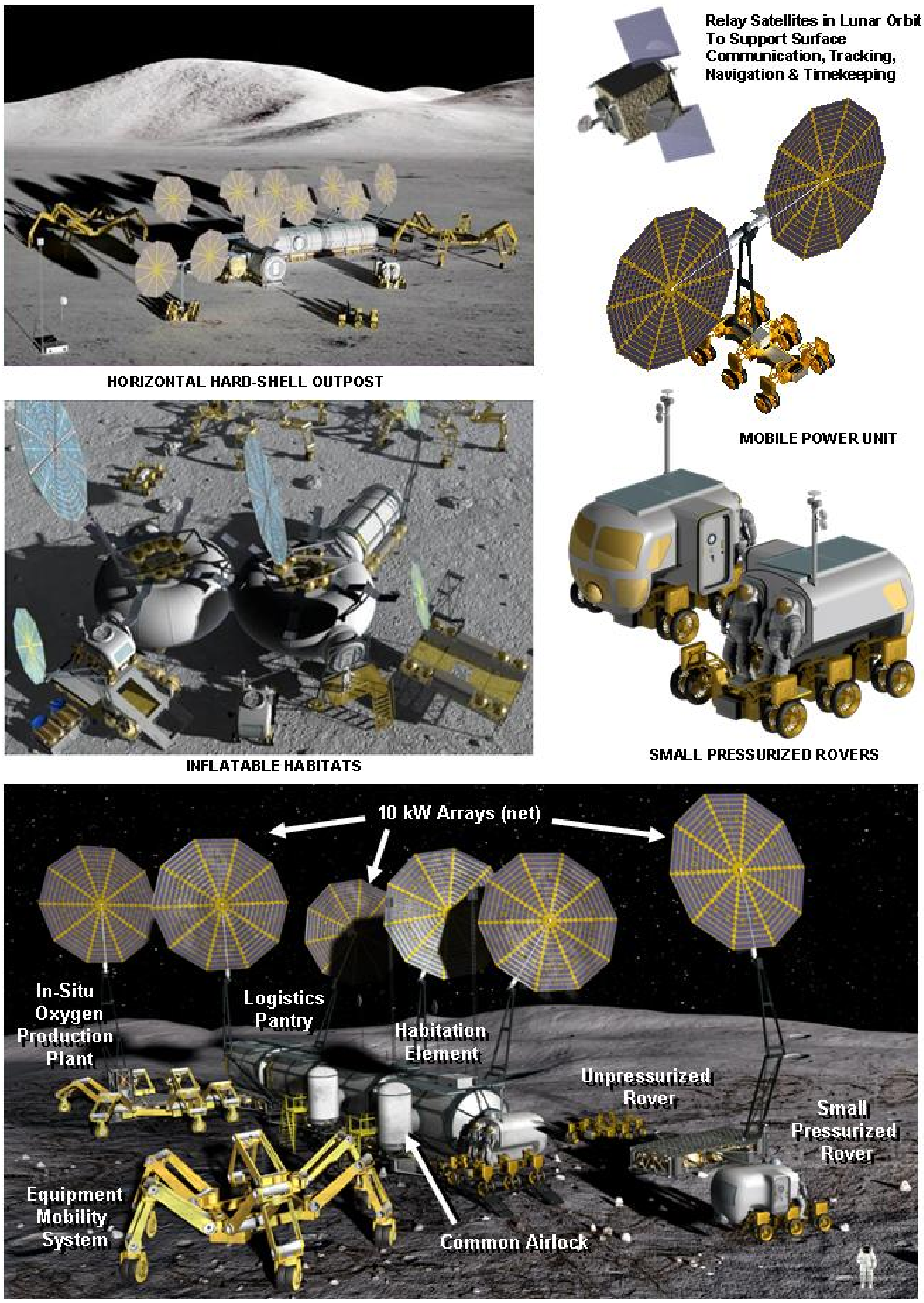


Figure 1-6. A variety of feasible concepts for an initial Lunar Surface Outpost.

1.7 Why the Moon?

The Moon offers intriguing scientific opportunities and a unique test bed to develop and perfect the technology necessary to begin long-term, extended exploration of the Moon and Mars, and to use the vast natural resources available beyond the Earth. Unlike Mars or other locations, the Moon can be reached with existing or derived launch and environmental support systems. From the brief Apollo explorations, we know that the lunar surface is rich in materials necessary for extended operations and that lunar soil can be a fertile growth medium for terrestrial plants and can be used for building material and insulation from solar radiation. In addition to silica, iron, titanium, and small amounts of hydrogen and helium from the solar wind, most lunar rocks are approximately 40% oxygen. In-situ (i.e., on-site) production of exploration staples such as water, oxygen, rocket fuel, solar cells, and other building materials should be possible, and the lunar environment offers some unique environmental advantages (e.g., unfiltered sunlight for power generation and low gravity and pressure to support a vacuum deposition manufacturing process). Some of these same characteristics will pose special problems for equipment and human health maintenance (e.g., extended exposure to a low-gravity environment and potential concerns about exposure to fine-powdered silicates) which will need to be quantified and overcome by human experience in an environment which is impossible to accurately simulate on the Earth.

The transport systems and processes which we develop to reach the Moon can also be used to access geosynchronous Earth orbit, various areas of gravitational stability (Lagrange Points) within the Earth-Moon system (these locations are ideal for long-term astronomical telescopes and scientific platforms), and a variety of Earth-approaching asteroids. Experience with complex crew-rated engine system reliabilities will be critical for more long-term exploration missions in the future.

Perhaps most significant, the Moon is a 'natural space station' that is only 3 days away in transit time (and 3 seconds away for round-trip communication – as opposed to a gap of between 8 minutes and 40 minutes for round-trip communication between Earth and Mars, depending on orbital alignment of the planets). This physical and communication proximity may be as important for psychological considerations in our early exploration as it is for treating medical emergencies, transferring emergency supplies, or mounting a rescue mission.

Mars is a thousand times farther away than the Moon; perhaps greater than a 2-year minimum round trip. The complexity and expense of a human Mars mission will be orders of magnitude greater than lunar operations. The long-term lunar outpost will allow the perfection of the necessary engineering technology and techniques close to home, and perhaps give us the experience and confidence to build international relationships with which to share the Mars human exploration adventure.

1.8 Summary

In response to Presidential and Congressional direction following the Space Shuttle *Columbia* accident in 2003, NASA conducted the Exploration Systems Architecture Study using internal and independent expertise, and identified the key elements and milestones necessary to enable human exploration and exploitation of the Moon and to develop a long-term space infrastructure that will permit evolutionary growth and the future human exploration of Mars and other parts of our solar system. The Constellation Program began in 2005 with the goal of a first crewed mission in 2015 and a sustainable human return to the Moon by 2020.

In 2006, the new NASA Strategic Plan[10] outlined and adopted six strategic goals in support of this new agency direction:

- Strategic Goal 1: Fly the Shuttle as safely as possible until its retirement, not later than 2010.
- Strategic Goal 2: Complete the ISS in a manner consistent with NASA's International Partner commitments and the needs of human exploration.
- Strategic Goal 3: Develop a balanced overall program of science, exploration, and aeronautics consistent with the redirection of the human spaceflight program to focus on exploration.
- Strategic Goal 4: Bring a new CEV into service as soon as possible after Shuttle retirement.
- Strategic Goal 5: Encourage the pursuit of appropriate partnerships with the emerging commercial space sector.
- Strategic Goal 6: Establish a lunar return program having the maximum possible utility for later missions to Mars and other destinations.

The Constellation Program is a key participant in all of these goals except the retirement of the Space Shuttle. Work has begun to design, manufacture, and test the necessary hardware and software. New, cost-effective and efficient approaches are being adopted (e.g., ongoing review by external experts, concurrent short-term and long-term design compatibility development, new applications of risk reduction and manufacturing techniques, and in situ lunar resource utilization planning, to name a few). New emphasis is being placed on international cooperation, both with existing partners and with new, non-traditional participants (e.g., China, India, and the Republic of Korea). New opportunities are being studied to encourage commercial space development and to inspire a new generation of scientists and engineers in our educational system.

All of the critical design and development activities described in this paper establish the foundation for a U.S. Lunar Capability that will enable humans to depart low Earth orbit for the first time in nearly 40 years.

Figure 1-7 shows a variety of Constellation activities currently underway across the country.

Figure 1-7. A small sample of Constellation design and test activities underway prior to beginning test flights in 2009. *Photo Key: 1) Orion flight test crew capsule prepared for testing at Glenn Research Center. 2) Ares I first stage main parachute test. 3) Crew capsule launch abort system jettison motor test. 4) Crew capsule airbag drop tests. 5) Abort flight test launch pad under construction in White Sands, New Mexico. 6) Crew seat and harness testing underway on acceleration sled at Wright Patterson Air Force Base. 7) Launch abort motor full scale test stand in Promontory, Utah. 8) Prototype lunar surface spacesuit and lunar rover vehicle testing at Johnson Space Center. 9) Crew module arrives at Dryden Flight Research Center for PA-1 test launch. 10) Ares-V RS-68 core stage engine test firing at Stennis Space Center. 11) Crew module preparation area at Dryden for Pad Abort and Ascent Abort launch tests.*

2.0 Constellation Program: Major Vehicles, Hardware, and Facilities

The Constellation Program is developing the flight systems and Earth-based ground infrastructure for an expanded human presence in the Solar System. Building on the achievements of previous lunar exploration efforts and much technological advancement made over the past 5 decades, this evolving infrastructure will provide the foundation for the United States to continue to access the ISS, return humans to the Moon, and enable human exploration of Mars and beyond.

The first step in this ambitious national undertaking is to formulate a safe, cost-effective and sustainable strategy, or architecture, for lunar return and then design and develop the building blocks of vehicles and systems necessary to accomplish this goal. Figure 2-1 illustrates the basic plan (reference mission) for the first human lunar landings.

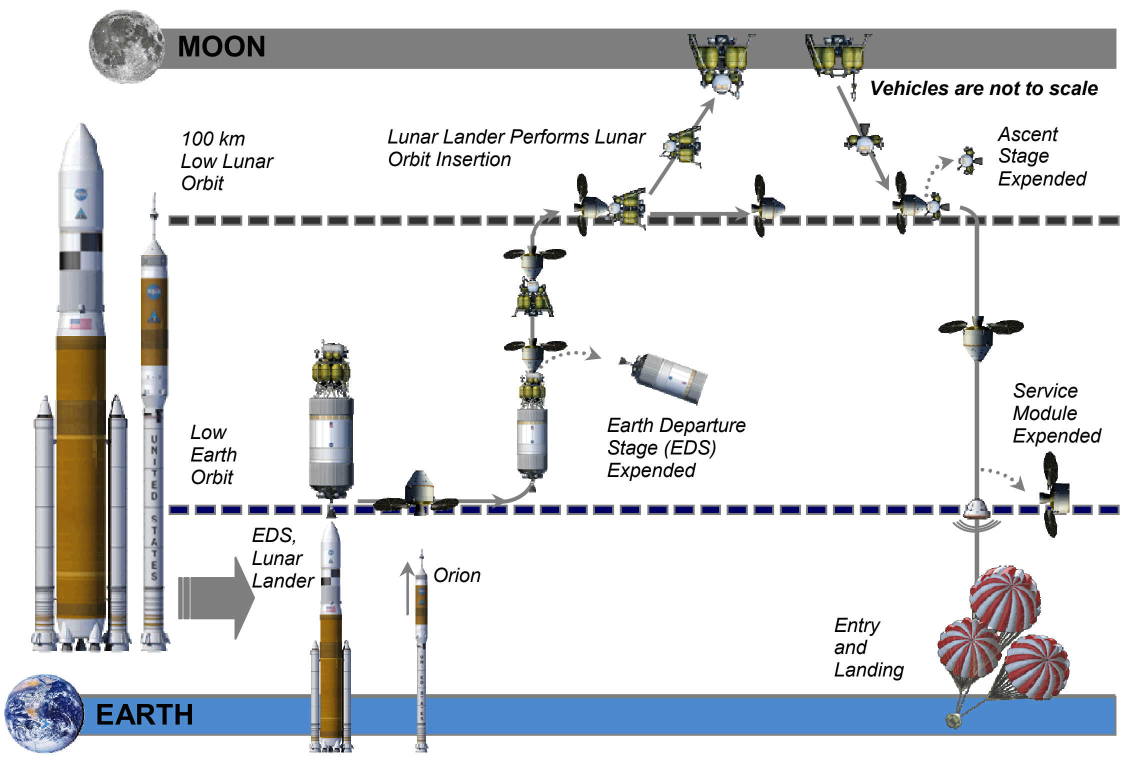


Figure 2-1: Reference mission profile for the first human lunar return flight.

For these missions, the Altair lunar lander vehicle is mated with the Earth Departure Stage (EDS) booster and launched on the heavy-lift Ares-V rocket. For safety and cost considerations, this new architecture stresses the separation of crew from cargo launches (it is easier and less expensive to human-rate the smaller and less complicated vehicle required for crew transport). The crew will launch in the Orion CEV on the Ares I rocket. The Orion CEV will rendezvous and dock with the Altair/EDS. The EDS will perform the trans-lunar injection burn necessary for the integrated Orion CEV/Altair vehicle to leave Earth orbit and begin a coast trajectory to the Moon. During this coast phase, the EDS is jettisoned after its fuel is spent. Upon arrival at the Moon, the Altair lunar descent engine is used to reduce the vehicle’s velocity and enter lunar orbit. The crew then transfers to the Altair lander (unlike the Apollo missions, there are no plans to leave an astronaut in lunar orbit), separates from the Orion spacecraft and descends to the lunar surface. Unlike Apollo, which could only reach equatorial regions of the Moon, Altair will carry enough fuel to land in all lunar regions, including the poles. Once the surface mission is complete, the crew will use the Altair ascent stage to lift off from the lunar surface, leaving the descent stage on the lunar surface. Once the crew has docked and transferred to the orbiting Orion CEV, the Altair ascent stage is jettisoned to the lunar surface.

The primary infrastructure components necessary to accomplish this mission are:

- The Orion CEV, comprised of a Crew Module, Service Module, Launch Abort System, and spacecraft adapter hardware which attaches the Orion spacecraft to the Ares launch vehicle.
- The Ares I rocket, the launch vehicle for the Orion CEV.
- The Ares V rocket, a heavy-lift vehicle designed to launch the Altair lunar lander (or any heavy payload element) and an EDS rocket.
- The Altair lunar lander, which includes a crew cabin with lunar descent and ascent stages.
- EVA support hardware, which includes new tools and spacesuits for crew work in space and on the lunar surface.
- Lunar Surface Systems equipment for advanced lunar operations, including rovers, habitat and logistics modules, communication and power systems, and other hardware needed for extended stays on the lunar surface.
- Mission and Ground Operations facilities, including launch pads and launch control center, vehicle integration and test facilities, recovery and refurbishment facilities, the mission control center, and various engineering and training support facilities.

2.1 The Orion Crew Exploration Vehicle

The basic design of the Orion spacecraft consists of the Crew Module, Service Module, Spacecraft Adapter, and Launch Abort System (see figure 2-2). The Orion spacecraft is approximately 5 meters (m) (16.4 feet [ft]) in diameter and 15.3 m (50.3 ft) in length with a mass of approximately 14,000 kg (31,000 lb). The Orion spacecraft provides crew habitation in space; docking capability with other launched components and the ISS; and performs Earth return, atmospheric entry, and landing. The Orion spacecraft can be configured to carry a crew of up to four to and from lunar orbit and up to six to and from the ISS.

Due to the physics associated with atmospheric entry, the overall shape of the Crew Module is similar to that of the Apollo Command Module; however, the Orion Crew Module is much larger, providing more than twice the usable interior volume and carrying double the crew size to the Moon. The Crew Module includes a pressurized crew transfer tunnel and docking device capable of mating with the ISS and the Altair lunar lander.

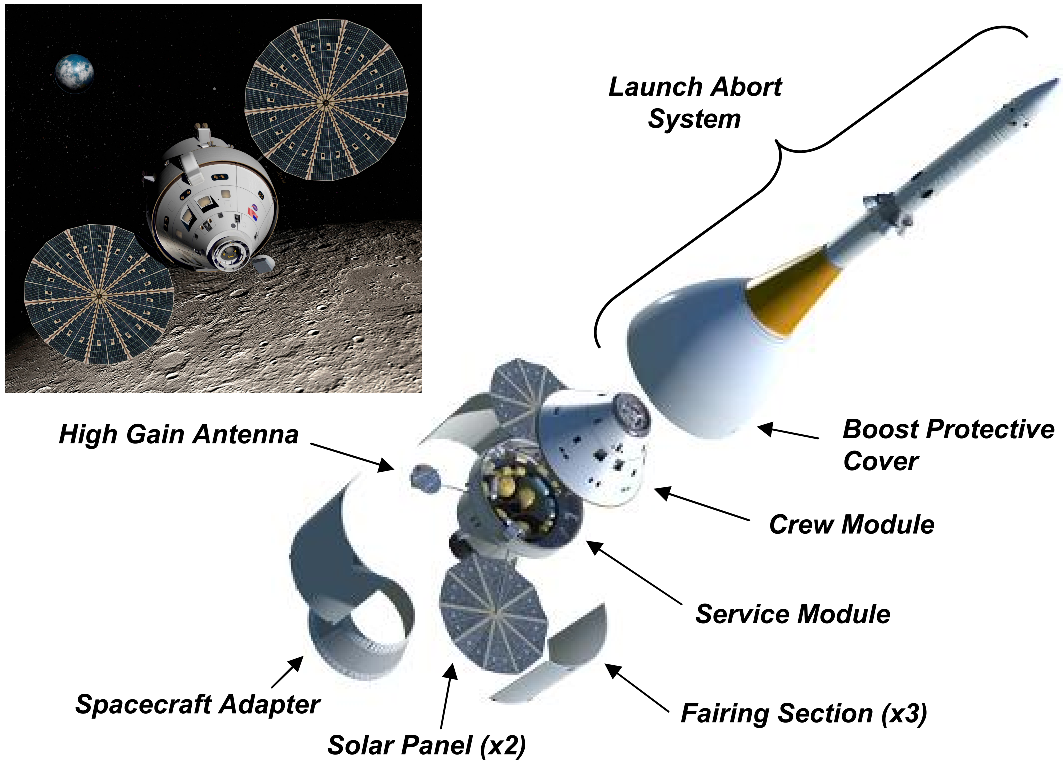


Figure 2-2. Orion Crew Exploration Vehicle.

New features of the Orion spacecraft include a digital “glass cockpit” control system, derived conceptually from the systems used in today’s most advanced aircraft, and the use of high-data-rate, low-weight fiber optic systems. The spacecraft will be able to "autodock" with the ISS using onboard sensors and computers, with provision for the crew to take over in an emergency. Previous American spacecraft (Gemini, Apollo, and Shuttle) have all required manual piloting for docking. The final interior layout of the Crew Module and its controls are still being designed, but a reasonable representation is shown in figure 2-3.

The primary landing mode for the Crew Module will be an ocean landing near the western U.S. coast supported by parachutes and inflatable water flotation airbags; however, contingency landing and recovery of the crew and capsule will be possible anywhere in the world. Current planning is focusing on a nominal water landing, within 200 miles of the Navy’s San Clemente Island Range Complex, using a local retrieval ship with helicopter support and cost-sharing of a Deep Submergence Rescue Vehicle with the Navy and Military Sealift Command.

After recovery, various components of the Crew Module will be refurbished and reflown. Hardware associated with Launch Abort System, Service Module, and Spacecraft Adapter is jettisoned at various points during the flight and either disintegrates during atmospheric reentry or is targeted for impact in a remote ocean location.

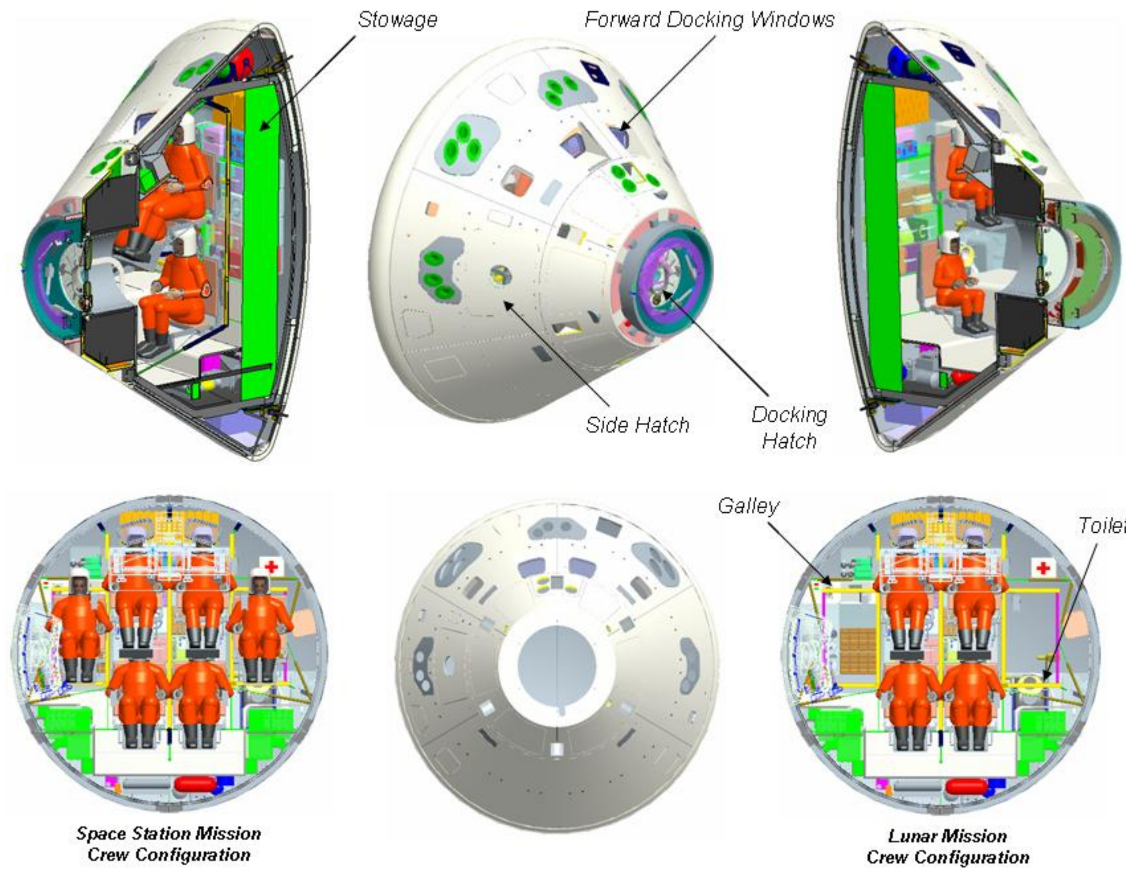


Figure 2-3. Proposed interior of the Crew Module (which is in the detail design phase).

Prior to splashdown, the Crew Module will encounter high aerodynamic heat loads from the Earth's atmosphere, just as the Apollo Command Module did as it returned from the Moon, and as the Space Shuttle does on its gliding descent from low Earth orbit. Thermal protection of the crew capsule is a significant design challenge. Orion's Crew Module Thermal Protection System consists of an expendable heat shield on the bottom of the spacecraft and reusable external and internal insulation. A number of candidate materials were evaluated for use in the thermal protection system (e.g., silica, carbon fibers, ceramics, and combinations of these materials). Avcoat, a low-density, glass-filled epoxy resin used during the Apollo Program, is the currently preferred material based on the test results so far. Unlike the thermal protection system used on the Space Shuttle, the Orion heat shield will not be exposed during launch, ascent to orbit, or during operations in space (it is exposed only after separation from the Service Module just before reentry), so extensive in-space inspections and repair capability will not be necessary.

The Orion Service Module is a cylindrical structure attached aft of the Crew Module and contains propulsion and power systems (including two large deployable circular solar arrays), a high-gain antenna for communication, and the radiator panels used to reject heat developed within the Crew Module (see figure 2-4).

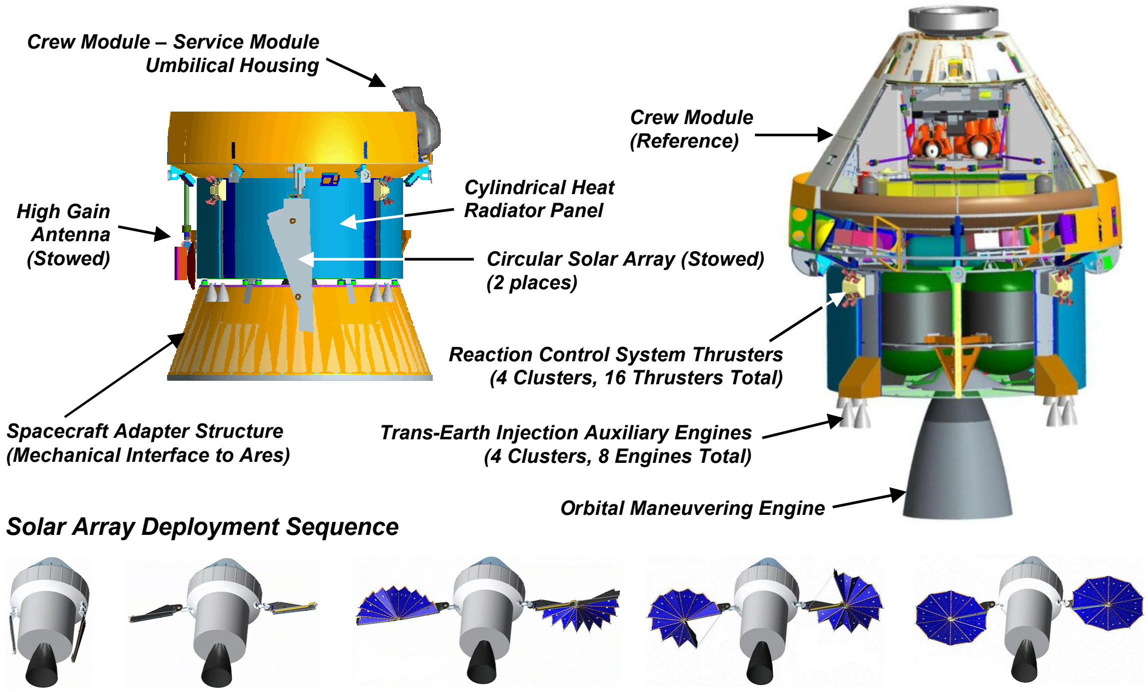


Figure 2-4. Orion Service Module.

Should an emergency situation arise during launch or early ascent operations, rapid escape of the crew from the Orion/Ares I launch stack is accomplished by means the Launch Abort System, which is essentially a smaller solid rocket motor and guidance control system mounted on top of the Orion Crew Module (see figure 2-5). This is a significant safety improvement over the design of the Space Shuttle. In an emergency, pyrotechnics will separate the Crew Module from the Service Module and the Launch Abort System rocket will pull the Crew Module away from the remainder of the launch vehicle stack. Once the Crew Module is clear of danger, the Launch Abort System and Boost Protective Cover assembly are jettisoned and the Crew Module returns to Earth using its normal landing parachutes. This system is being designed to operate in all critical phases of launch and ascent: from a zero-velocity start (a launch pad accident prior to liftoff) and at either subsonic or supersonic phases of the ascent profile. The Launch Abort System rocket motor itself is more powerful than the Atlas 109-D booster that launched John Glenn into orbit in 1962.

During a routine launch, the Launch Abort System will be jettisoned approximately 30 seconds after First Stage separation and will splash down in the Atlantic Ocean. After the Launch Abort System is jettisoned, emergency abort capability for the crew is provided by the Service Module propulsion system.

> ***The Orion/Ares I is estimated to be as much as 10 times safer for the crew than the Space Shuttle, primarily due to its in-line design and incorporation of the Launch Abort System for crew escape.***

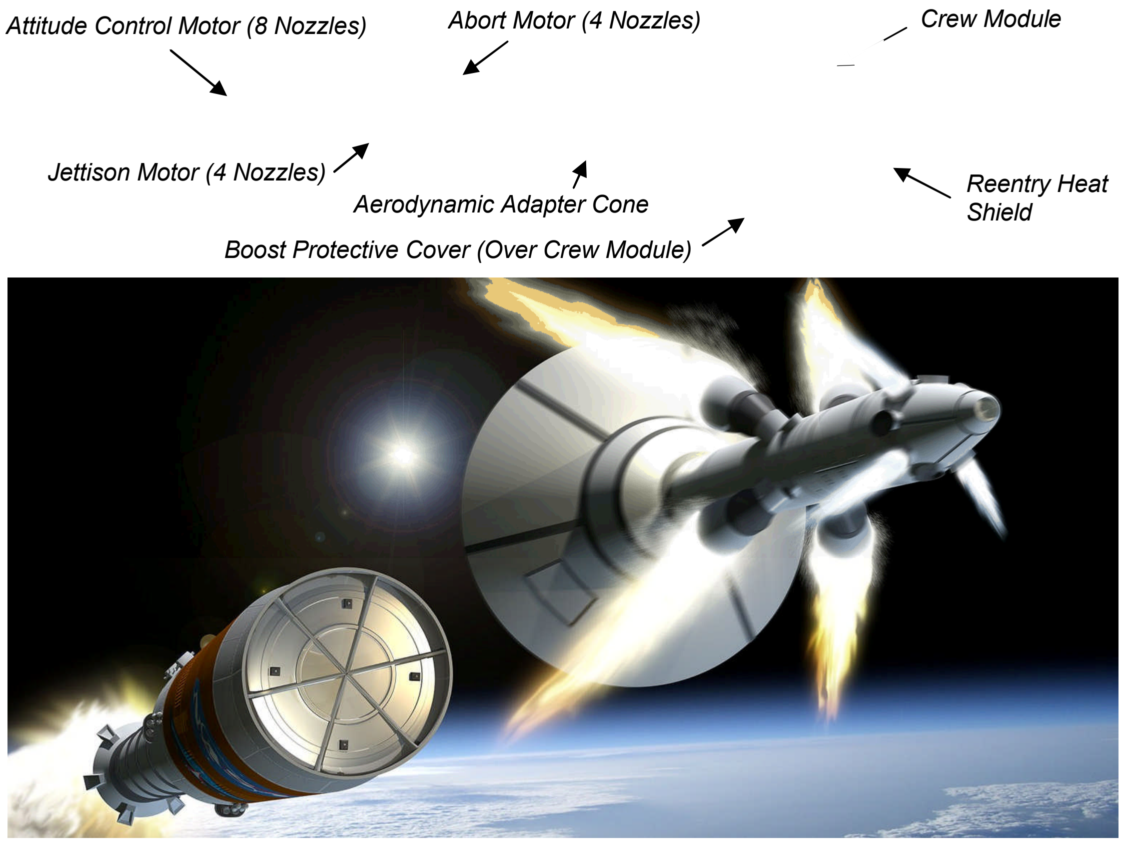


Figure 2-5. The Orion Launch Abort System for crew escape during a launch emergency.

The Service Module is connected to the Ares I launch vehicle by the Spacecraft Adapter, which consists of a W-Truss and a fairing. The Spacecraft Adapter provides a smooth physical transition from the Ares I Upper Stage to the Orion and a conduit for data transfer between the vehicles. This arrangement allows structural load sharing between the Service Module internal structure and the fairing during peak loading events of the ascent phase, but allows the fairing to be jettisoned once the vehicle has left the atmosphere. The Spacecraft Adapter fairing sections also provide protection for the Service Module structure (including the main engine, the solar arrays, and the high-gain antenna) during ascent. After main engine cutoff, the Spacecraft Adapter, now without the fairings, remains attached to the Ares I Upper Stage while the Service Module separates and continues into orbit.

2.2 The Ares Launch Vehicles

The Ares I launch vehicle carries the Orion spacecraft to low Earth orbit where it can rendezvous and dock to the ISS or to the Altair lunar module previously launched by an Ares V heavy-lift rocket. Components of the Ares I and Ares V launch vehicles are being developed concurrently with propulsion and structures hardware commonality, which results in significant design and manufacturing cost savings. Common elements being developed for the Ares I and Ares V launch vehicles include the solid rocket motors and the J-2X Upper Stage engine. Cost and risk reduction are also enhanced by using existing and proven hardware and systems whenever possible. This includes Solid Rocket Booster technology from the Space Shuttle Program used as the basis for the Ares I First Stage and Ares V booster rockets. The Ares I Upper Stage J-2X engine and the Earth Departure Stage engine of the Ares V are generational upgrades of the J-2 engine used on Saturn V and Saturn IB launch vehicles during the Apollo Program. The RS-68 engines of the Ares V core stage were developed in the late 1990s and early 2000s for the U.S. Air Force's Evolved Expendable Launch Vehicle Program (Delta IV).

2.2.1 The Ares I Launch Vehicle

The Ares I is a two-stage launch vehicle (see figure 2-6). The First Stage is a five-segment Solid Rocket Booster fueled with approximately 1.4 million pounds of solid propellant. The Upper Stage is a structurally self-supporting cylindrical system that houses the liquid oxygen and liquid hydrogen tanks that contain propellant for the single J-2X engine, along with the avionics, roll control, and thrust vector control systems.

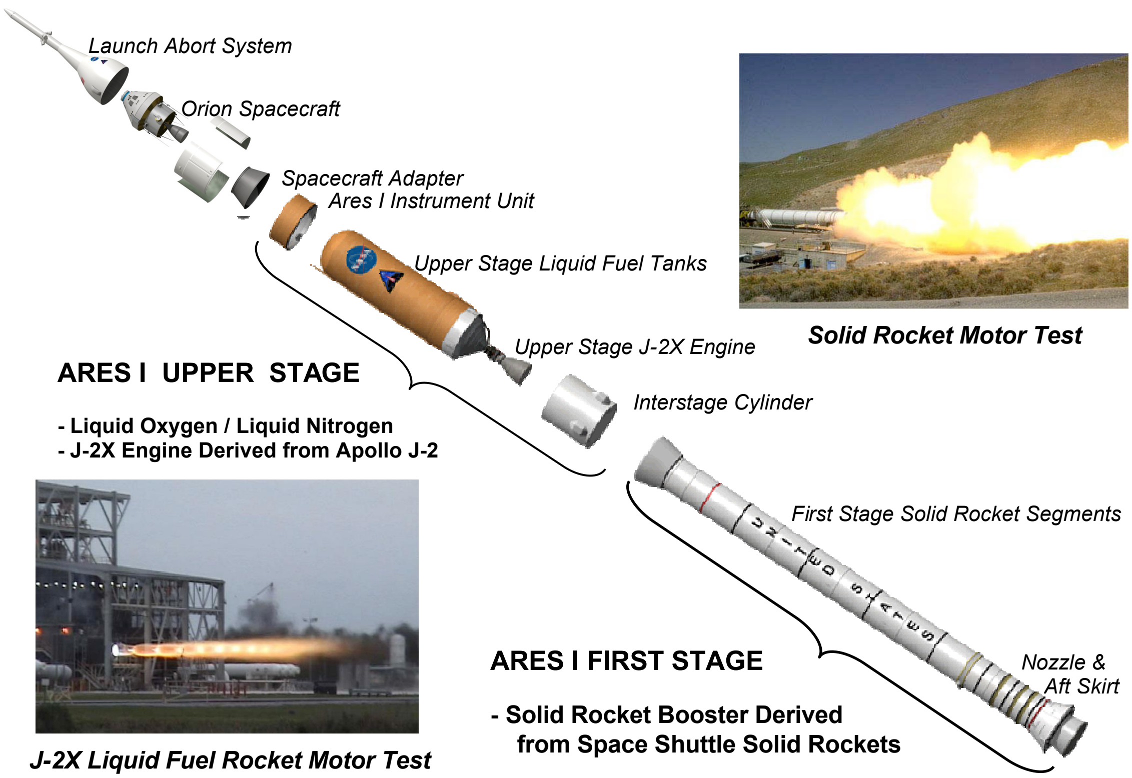


Figure 2-6. The Ares I Launch Vehicle.

During a mission, the Ares I First Stage will be jettisoned a little more than 2 minutes after launch. A parachute system will allow the First Stage to be recovered from the Atlantic Ocean and returned to Kennedy Space Center for disassembly and cleaning. The solid rocket motor casings will be returned to Utah for refurbishment and refueling. Other components of the First Stage (e.g., separation motors and parachutes) will be refurbished at Kennedy Space Center. The Constellation Program is studying the possibility of not recovering the spent Ares I First Stage for certain missions. This could gain additional performance margin for certain missions by eliminating the launch weight of the booster recovery systems (e.g., parachutes, transponders, flotation devices, etc.).

The Upper Stage will separate from the Orion spacecraft after main engine cutoff. The Upper Stage will enter the Earth's atmosphere and splash down in the Indian Ocean (see figure 2-7).

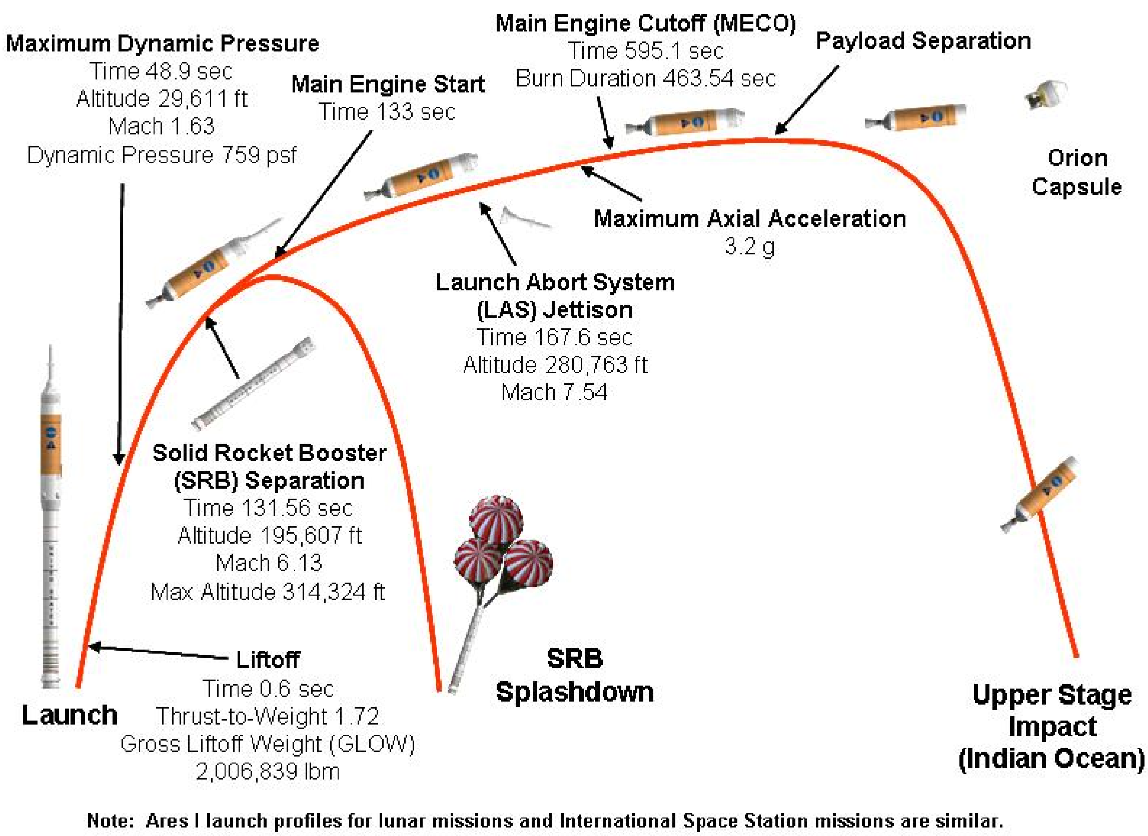


Figure 2-7. Orion/Ares I mission profile to low Earth orbit.

2.2.2 The Ares V Launch Vehicle

The Ares V launch vehicle provides heavy-lift capability. The vehicle is roughly 110 m (360 ft) tall and will lift 143.4 mT (316,100 lbm) to low Earth orbit or propel 55.6 mT (122,600 lbm) on a lunar trajectory. The 143 mT to low Earth orbit compares to a maximum payload capacity of approximately 25 mT for the Space Shuttle. In its current design configuration, the Ares V consists of a liquid oxygen/liquid hydrogen propellant Core Stage with two Solid Rocket Boosters and an Earth Departure Stage derived from the Ares I Upper Stage. Atop the Earth Departure Stage is a payload shroud to protect the payload for lunar and future Mars missions (see figure 2-8).

The Ares V Core Stage leverages manufacturing processes and materials used on the Space Shuttle External Tank (ET). The Core Stage is 10 m (33 ft) in diameter and 65 m (212 ft) in length, making it the largest rocket stage ever built. It is roughly the same diameter as the Saturn

V First Stage, but its length would be about the same as the combined length of the Saturn V First and Second Stages. The Core Stage will use a cluster of six RS-68B liquid hydrogen/liquid oxygen engines, each supplying about 3.1 million N (700,000 lbf) of thrust.

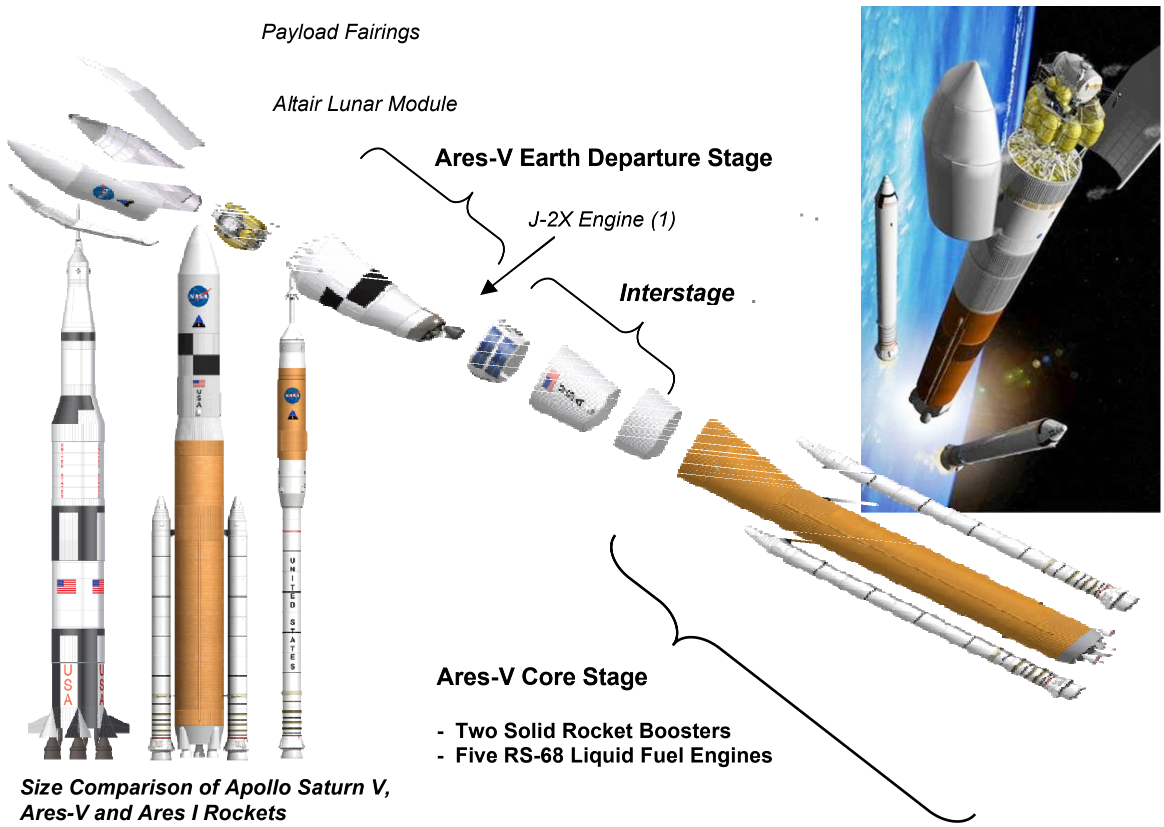


Figure 2-8. The Ares V Launch Vehicle.

The two Ares V Solid Rocket Boosters are derived from the Solid Rocket Boosters (SRBs) currently used on the Space Shuttle and from the First Stage planned for the Ares I. These solid boosters will separate from the Core Stage during ascent and be recovered in the Atlantic Ocean. The Constellation Program is studying the possibility of not recovering the spent Ares V SRBs for certain missions. This could gain additional performance margin for certain missions by eliminating the launch weight of the booster recovery systems.

The Second Stage of the Ares V is called the Earth Departure Stage. The Earth Departure Stage is powered by one J-2X engine developed for Ares I but modified with an air restart capability. The Earth Departure Stage has two functions: 1) provide a suborbital burn to place the lunar payload into a stable Earth orbit; and 2) ignite a second time after the Orion spacecraft, launched separately on an Ares I, docks with the Earth Departure Stage to place the combined vehicle into a trajectory toward the Moon.

2.3 The Altair Lunar Lander

The Altair Lunar Lander will provide access to the lunar surface for astronaut crews and/or cargo via a descent stage and will return the crew via an ascent stage to the Orion spacecraft in lunar orbit. A cargo-only version of the Lunar Lander will be able to transport cargo to the lunar surface and may not include an ascent stage. Basic elements of the Lunar Lander will include the propellant tanks and engines associated with the ascent/descent stages, a living module for the crew (i.e., pressure vessel), a landing gear system, internal power supplies (e.g., rechargeable batteries) and provisions for crew access to the lunar surface. Propellants proposed for the Lunar Lander include liquid oxygen/liquid hydrogen for the descent stage and liquid oxygen/methane for the ascent stage; although a final decision on propellants has not been made.

After the Earth Departure Stage is jettisoned, the astronauts will pilot the docked Altair and Orion spacecraft on to the Moon. In lunar orbit, the Orion crew will transfer into the Altair lander (unlike the Apollo missions, an astronaut will not remain behind in lunar orbit), undock from the Orion CEV and fly to the lunar surface. During the surface mission, the Orion spacecraft is monitored from Mission Control and held in a 'station keeping' mode in lunar orbit. When the surface mission is complete, the crew will fire the Altair ascent stage to lift-off from the lunar surface, leaving the descent stage behind. Once the crew docks and moves into the orbiting Orion CEV, the Altair ascent stage is jettisoned and targeted for impact on the lunar surface. Figure 2-9 shows two conceptual designs for the lunar lander, which is still in the design phase. An important common characteristic of these designs are the large descent stage fuel tanks. This amount of fuel enables the lander to reach any point on the lunar surface, rather than being restricted to regions near the lunar equator, as was the Apollo Program. Figure 2-10 illustrates the ascent stage after liftoff from the lunar surface and docking with the CEV.

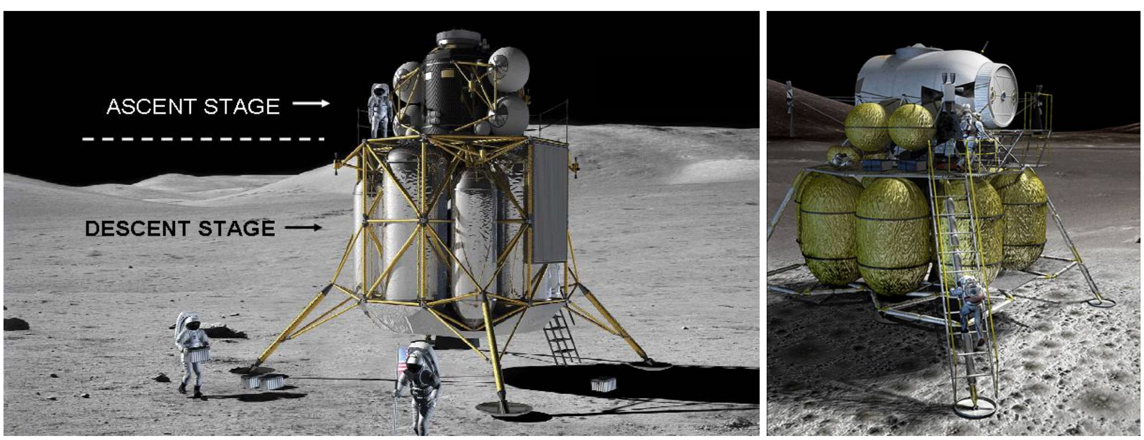


Figure 2-9. Conceptual designs for the Altair Lunar Lander.

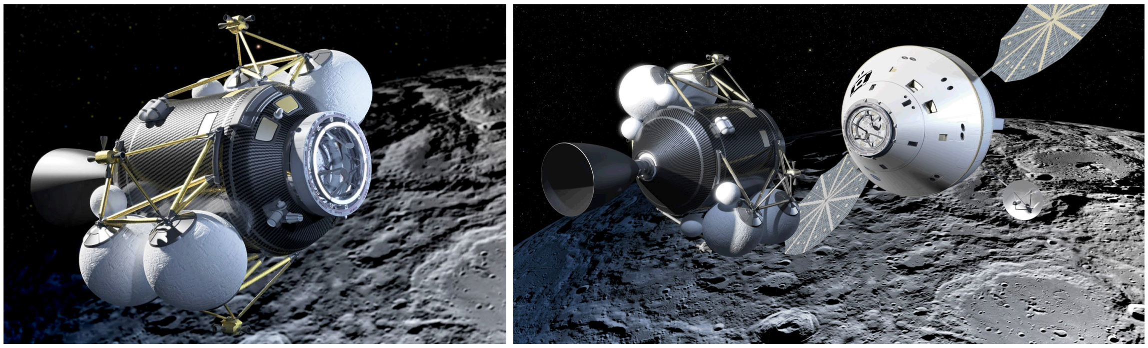


Figure 2-10. Ascent stage returning to Orion after liftoff from the lunar surface.

2.4 Extravehicular Activity Systems

The EVA Systems Project provides the spacesuits and necessary tools for astronauts to work outside of the protective confines of a space vehicle. EVAs can be conducted in space or on the lunar surface, and are used for planned activities, such as research tasks or site exploration, and for contingency tasks, such as inspection or vehicle repair.

The EVA Systems Project will develop, certify, produce, and sustain flight and training hardware systems necessary to support EVA and crew survival during all Constellation mission phases.

The following spacesuit capabilities are being developed:

- Crew protection and survival capability for launch and atmospheric entry, landing, and abort scenarios.
- Contingency zero-gravity in-space EVA capability for the Orion spacecraft.
- Surface EVA capability for exploration of the Moon.

The spacesuit, called the Extravehicular Mobility Unit, currently being used by the Space Shuttle Program and on the ISS is not compatible with either the lunar or the Martian environments because it was designed for zero-gravity operations in low Earth orbit. NASA is developing a new modular spacesuit system that will be used during launch, atmospheric entry, abort, in zero-gravity and in lunar environments. The spacesuit will support long-duration (180 days) missions, perform multiple EVAs, and function under conditions expected at lunar exploration sites. Figure 2-11 illustrates the two basic types of spacesuits being developed: the Launch-Entry-Abort Suit and the Lunar Surface Suit. These designs share many common elements, but the Lunar Surface Suit provides additional micrometeoroid and dust protection and has an enhanced range of mobility to allow astronauts to work for extended periods of time in the lunar 1/6-gravity environment. Figure 2-12 shows engineers testing a prototype Lunar Surface Suit in conjunction with a new lunar rover concept vehicle at Johnson Space Center in early 2008.

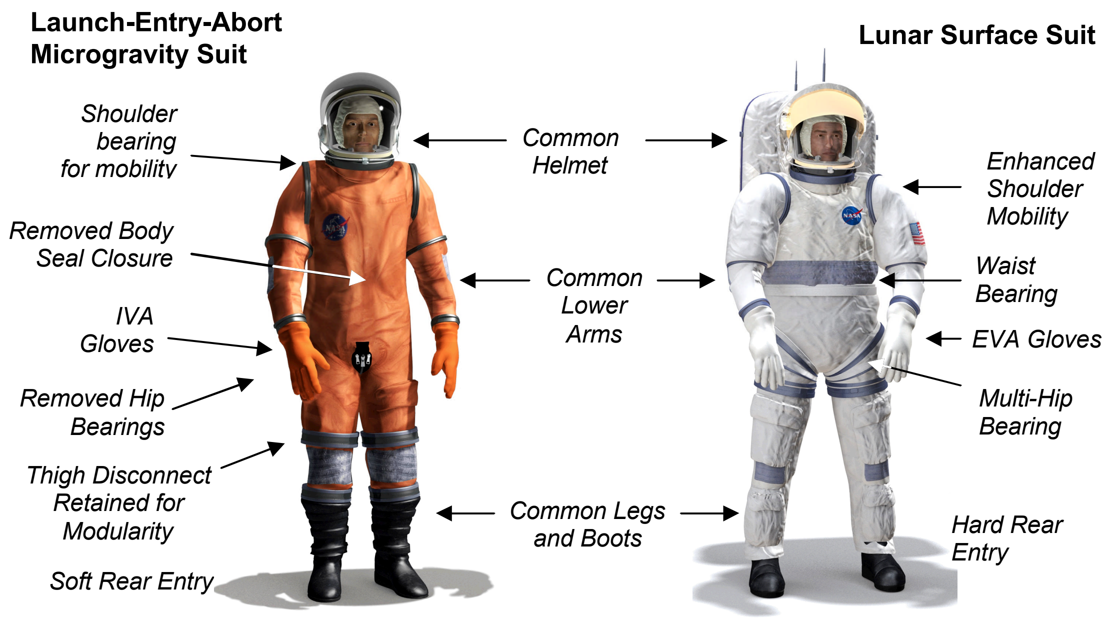


Figure 2-11. Early designs for the launch-entry-abort suit and lunar surface suit.

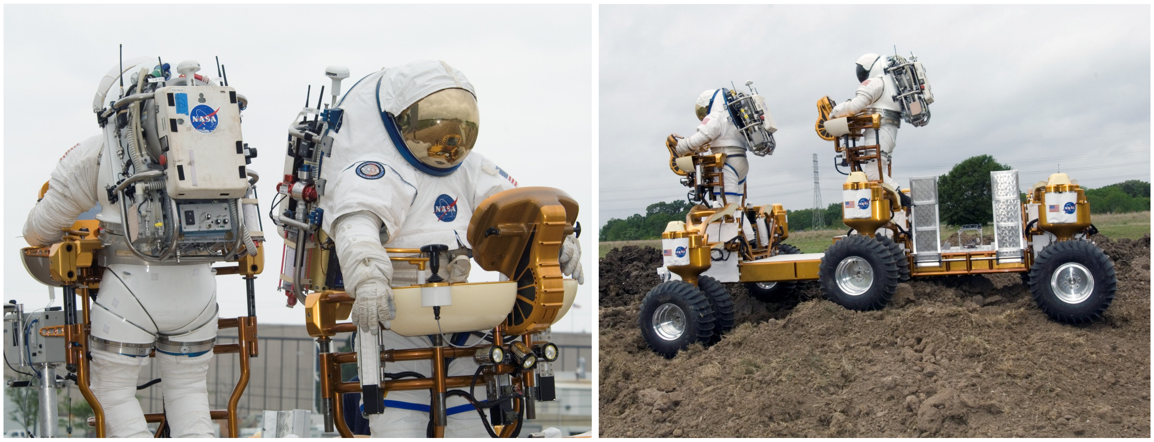


Figure 2-12. Prototype lunar surface suits are tested in early 2008 in conjunction with an omni-directional lunar rover concept vehicle (the "lunar truck") developed at NASA. These designs and tests will help establish performance requirements and a baseline for evaluating future proposals.

2.5 Lunar Surface Systems

The primary goal of developing the launch capability and the vehicle and suit infrastructure is to enable a sustained human presence on the Moon. In June, 2008, the Constellation Program completed the LCCR. The LCCR was a major milestone and the result of over 9 months of various lunar exploration-related studies, including:

- Lunar exploration requirements definition.
- Lunar surface infrastructure compatibility and maximum leverage with the Orion, Altair, and Ares vehicles already in development.
- Lunar mission concept evaluations.
- Habitat and logistics module concepts (hardside and inflatable).
- Lunar rovers and equipment mobility devices.
- Construction equipment concepts for lunar soil excavation and movement.
- Equipment and processes for oxygen extraction from lunar soil.
- Lunar surface communications and navigation services.
- Outpost evolution and growth (in both lunar equatorial and polar regions).
- Lunar infrastructure extensibility to Mars exploration.

The Lunar Surface Systems Project is tasked with continuing study and definition in all of these areas, and more, to refine an overall architecture for lunar surface operations, as well as engaging the international community in preliminary discussions about long-term lunar outpost development. Figure 2-13 shows prototypes of lunar surface systems being tested at Moses Lake, Washington, in June 2008.

Figure 2-13. Prototype lunar surface systems testing. With mobile lunar habitat modules in the background, astronauts on a "lunar truck" deploy a robot scout rover. The lunar truck doubles as a bulldozer. An automated drilling unit makes its way over simulated lunar terrain. An electric crane is tested for removing equipment from a simulated lunar lander.

2.6 Ground Support Activities at the Launch Site and Other Test and Development Facilities for Constellation Missions

As the Orion and Ares vehicles are being designed, developed, and tested, a major refurbishment and update of launch site facilities to accommodate these new vehicles is underway at Kennedy Space Center. As the Space Shuttle Program proceeds toward a planned retirement in 2010, construction is already underway at Kennedy Space Center to convert existing facilities used during the Apollo and Space Shuttle Programs to support the new Constellation vehicles.

A primary goal of ground system planning has been to reuse as much existing infrastructure (processes and facilities) as possible, while minimizing operational costs. Orion spacecraft assembly and checkout will take place in the Operations & Checkout building originally used to assemble and test Apollo vehicles. Ares assembly and mating with the Orion CEV will take place in the familiar Vehicle Assembly Building (VAB) used for both Apollo and Shuttle missions. The existing (although modified) Mobile Launch Platforms, Crawler-Transporter vehicles, launch pads, and launch control center will also support Constellation launches. Figure 2-14 shows the VAB and an artist's concept of the Ares I vehicle assembled in the VAB High Bay and on the launch pad.

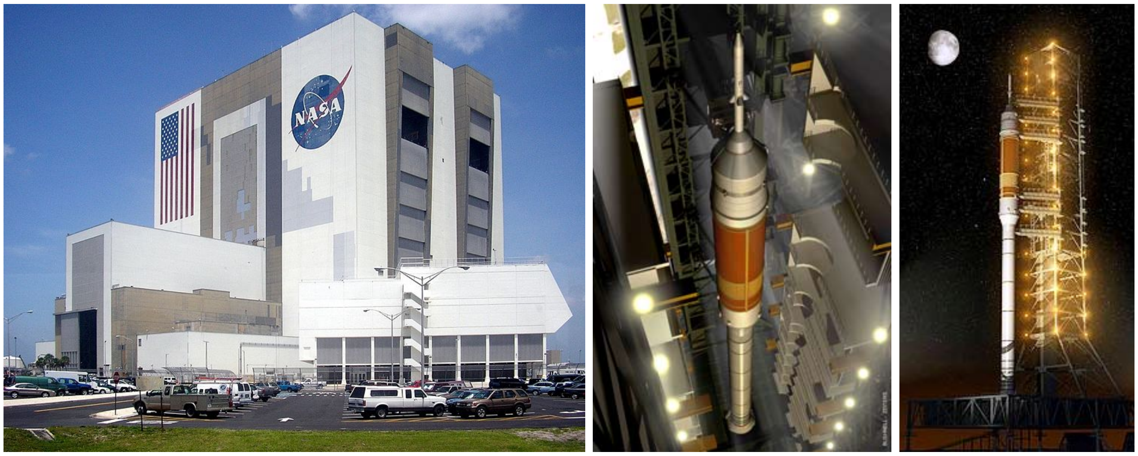


Figure 2-14. The Ares I vehicle will be assembled in the VAB High Bay 3 (the right-side set of vertical shutters in the photo), and the Ares-V will be assembled in the adjacent High Bay 1 area. Artists' concepts show the Ares I in VAB High Bay 3 and at launch pad 39B.

Launch complex 39 (launch pads 39A and 39B), currently used by the Space Shuttle, will be converted to support the Constellation missions. Modifications will begin on launch pad 39B to accommodate the Ares 1-X test flight immediately following its last use as a stand-by launch pad in the event that a rescue Space Shuttle mission is required to support the final Hubble Space Telescope repair mission in 2009. The Space Shuttle fixed and rotating service structures at the pad will be dismantled and a new fixed service structure for the Ares I will be permanently installed on the Mobile Launch Platform that will transport the vehicle from the VAB to the launch pad. Work will begin in 2010 following the last Space Shuttle launch to modify pad 39A for the Ares-V vehicle. Constellation has implemented a 'clean pad' design approach, which involves minimizing the interfaces to the launch vehicle on the launch pad. This approach is intended to simplify launch operations along with the timeline and costs associated with preparation of the vehicles for launch.

In addition to modifications to the VAB, launch pads, and mobile launch platforms, Firing Room 1 in the Launch Control Center is being redesigned to support Ares and Orion missions with improved computers and far fewer support personnel. While it currently requires more than 200 people in the Launch Control Center to launch a Space Shuttle mission, it is anticipated that the Constellation launch support team will number less than 50 people. This is the result of improved technology and the fact that the Constellation vehicles are a far less complex than the Space Shuttle.

In addition to work taking place at the launch site, the Constellation Program is modifying or constructing a number of support facilities that will help manufacture spacecraft, plan missions, train personnel, support flight operations, and test new vehicles and subsystems for spaceflight. One of our most fundamental program challenges is balancing the benefits of using heritage hardware and facilities versus the projected long-term cost of this use. Constellation is still in the process of examining all processes and procedures for optimization of cost and time resources. Significant facility projects underway include:

- Construction of a new rocket engine test platform at Stennis Space Center, Mississippi. The A-3 test stand, currently under construction, will allow full-scale testing of the J-2X engine at simulated high altitude. This is critical to assure restart capability of this engine for the lunar missions. The A-3 test stand is the first new full-scale engine test stand constructed at Stennis Space Center since the Apollo Program.

- Modifications to the Structural Dynamics Test Facility at Marshall Space Flight Center in Huntsville, Alabama. This facility was used to conduct full-scale ground vibration tests of the Apollo and Space Shuttle vehicles. It is being modified to conduct similar testing for the Constellation vehicles.

- Installation of the CEV Avionics & Integration Laboratory at Johnson Space Center in Houston, Texas. The laboratory is being constructed in the existing Building 29 and will contain vehicle mock-ups and computers to simulate mission phases and conduct end-to-end avionics testing in support of planning, pre-flight crew training, and real-time problem troubleshooting during actual missions.

- Upgrade of the Integrated Environment Testing (IET) facility at Plumbrook Station near Sandusky, Ohio (managed by the NASA Glenn Research Center in Cleveland). The existing IET facility is being refurbished to provide state-of-the-art test capabilities for full-size spacecraft. Complete Orion CEVs and Altair lunar landers will undergo vibration, acoustic, thermal, vacuum, and electromagnetic testing in the large IET chambers.

- Implementation of The Exploration Development Laboratory (EDL), a distributed software development and test facility that has linked facilities in Denver, Colorado; Houston, Texas; and Glendale, Arizona. The EDL performs systems-level avionics and software testing for Orion in realistic mission equipment configurations. The EDL became operational in late 2007 and has already begun software development, as well as initial testing of the Orion Guidance, Navigation, and Control subsystem, Automated Rendezvous and Docking subsystem, and crew interfaces.

- Modifications at Michoud Assembly Facility in New Orleans, Louisiana, (managed by the NASA Marshall Space Flight Center in Huntsville, Alabama). Michoud Assembly Facility will provide manufacturing and assembly facilities for large portions of the Orion, Ares I, and Ares V spacecraft. This facility has previous been responsible for manufacture of the Space Shuttle external fuel tanks, and contains one of the largest production buildings in the U.S.

- Construction of the Orion Flight Test Facility at the White Sands Missile Range in Las Cruces, New Mexico, will provide the integration area, control facilities, and launch pad necessary for the series of suborbital flight tests of the Launch Escape System.

In addition to these major, dedicated facilities, numerous existing government and contractor test facilities are supporting the Constellation Program for engine firings, thermal protection system sample tests, wind tunnel testing, material research, crew interface development, crew capsule drop tests, and many other design and development activities. A detailed description of the planned construction and modification of facilities in support of the Constellation Program can be found in the Final Constellation Programmatic Environmental Impact Statement.[11]

3.0 Constellation Missions: Flight Test, ISS Support, and Lunar and Mars Exploration

The Constellation Program is developing the first new human-rated spacecraft in 3 decades, and a comprehensive series of flight test activities are planned to find and fix any design problems, and verify and document vehicle performance capabilities (including safety designs) before crew flights begin.

Historically, flight test operations are unpredictable by nature, and this is especially true when new designs and new hardware are being tested for the first time in extreme operational environments. The Constellation Program fully expects to learn from failures during flight test activities, and to apply what is learned to make the operational Constellation vehicles the safest human spacecraft ever developed.

Beginning in early 2009 and lasting through 2012, flight test of the Orion Launch Abort System using a heavily instrumented, mass/dimension equivalent model of the Orion spacecraft will be conducted at the White Sands Missile Range in New Mexico. As currently planned, there will be two uncrewed pad abort tests (PA-1 and PA-2) to demonstrate Orion Crew Module escape on the launch pad from zero altitude and zero velocity and two uncrewed ascent abort tests (AA-1 and AA-2) to demonstrate a simulated crew escape during ascent of the vehicle after launch in critical phases of flight. (Refer to figure 2-8 for details of the Orion flight profile prior to Launch Abort System jettison.)

PA-1 and PA-2 will demonstrate the capability of the Launch Abort System to boost the Crew Module to an altitude sufficient to allow safe parachute deployment and to a sufficiently safe lateral separation from the launch site.

The ascent abort tests (AA-1 & 2) will use a launch vehicle being developed from surplus Air Force Peacekeeper first-stage and/or second-stage motors. This solid-fuel booster will launch the Crew Module to an altitude high and fast enough to test the Launch Abort System to operate at supersonic vehicle speeds, during periods of ascent profile maximum dynamic pressure, and during unstable (tumbling) flight modes. All flight test activities are designed to take place entirely within the White Sands Missile Range.

The first developmental flight test of the Ares I vehicle (designated Ares 1-X) will be an uncrewed launch from Kennedy Space Center in mid-2009. Test flight objectives will focus on first-stage flight dynamics, controllability, separation of the first and upper stages, ground operations, and first-stage recovery. Ares 1-X will test the integration and performance of a simulated Ares/Orion ‘stack’ prior to Ares I Critical Design Review so that any resulting design changes can be incorporated before production of flight articles begins. Ares 1-X utilizes a four-segment solid rocket booster excessed from the Space Shuttle Program, with a mass-simulator for the fifth segment. There will also be mass/dimension simulators for the upper stage and the Orion CEV. The solid rocket booster casing will be recovered from the Atlantic Ocean; the upper stage and CEV simulators will not be recovered. Figure 3-1 shows an artist’s concept of the Ares 1-X launch configuration and liftoff at pad 39B.

Figure 3-1. Left: Artist's concept of the Ares 1-X flight test configuration at Kennedy Space Center in mid-2009. Note that many pad elements from the Space Shuttle Program are still present at this time (e.g., the Rotating Service Structure on the right) and a lightning protection tower has been added atop the Fixed Service Structure to protect the increased height of the Ares vehicle. Right: Artist's concept of the Ares 1-X launch.

The second uncrewed flight test of the Ares I vehicle (designated Ares 1-Y) will also be launched from Kennedy Space Center. This flight test will consist of a five-segment booster with real upper-stage and simulated J-2X engine. The Ares 1-Y test flight will validate the operation of the Ares I five-segment first stage, and demonstrate performance of a high-altitude abort of the Launch Abort System with a boilerplate Orion capsule, after separation of the first stage. As with Ares 1-X, only the first-stage booster will be recovered from this flight.

The first orbital flight test of the Orion/Ares I vehicle is designated Orion-1. This will be an uncrewed first test flight of a complete Ares I first stage and operational upper stage, paired with an operational Orion CEV. The Orion CEV will be inserted into an orbit compatible with the ISS (although there are no plans to dock with the ISS on this first flight) to test onboard systems such as the solar panels, Reaction Control System thrusters, and main engine. A water landing and recovery off the coast of Australia is under study for this mission.

The first flight of the Constellation vehicle that will carry astronauts is designated Orion-2. This will be a two-crew mission which will rendezvous and dock with the ISS. After the Orion-2 mission, the Constellation vehicle will have achieved Initial Operational Capability and begin approximately two flights per year to the ISS to support crew rotations and to have the Orion spacecraft docked for 180-day intervals as an emergency crew return vehicle. Figure 3-2 illustrates the Orion CEV approach and docking to the ISS.

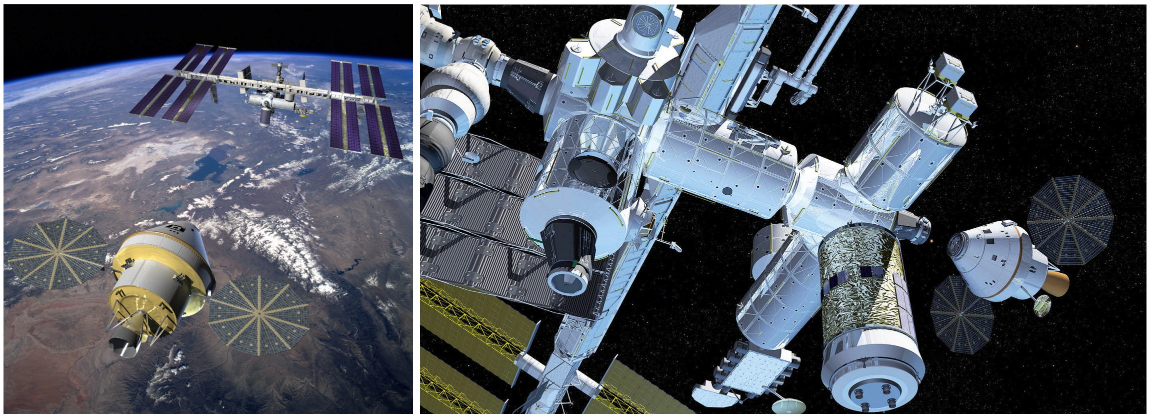


Figure 3-2: Artist's concept of Orion CEV approach and docking with the ISS.

In preparation for these first Orion missions, the Constellation Program is planning a series of two complete Virtual Missions in 2009 and 2010. The Virtual Missions will use existing software and hardware resources to simulate all critical mission milestones and products required to successfully execute an Orion to ISS crew rotation. This will include an end-to-end real-time simulation of all flight and ground phases (e.g., flight prep, launch, on-orbit ops, and reentry) that involves flight crew, flight control teams, and mission management teams.

The primary object of the Virtual Missions project is to exercise the data architecture and flight readiness certification process that will support the actual Orion missions. Engineering and management meetings leading up to these simulated missions will be conducted as if they were planning actual flights. These virtual missions (VM1 and VM2) have been added to the flight test manifest, and lessons learned from these simulations will be used to refine procedures, software, and the distribution of personnel across the support infrastructure (i.e., this will also serve as a high-fidelity test to determine the optimum number of support personnel needed during all phases of Orion ISS support operations).

After three crewed flights to the ISS between 2014 and 2015, when it is proven that the Constellation systems can operationally support the Orion vehicle with routine operations in Earth orbit to the ISS, the Constellation vehicle and ground support infrastructure will be certified for FOC with the Orion 4 flight. Based on the current budget, the Program is committed to FOC with Orion-4 in late 2015. Orion flights will provide space station crew rotation and serve as an emergency crew return vehicle while docked at the ISS for 6-month intervals. This will ensure that the international research facility is not dependent on a single vehicle design, or single government, for continued operation.

While the fully operational Constellation vehicles support research and engineering activities onboard the ISS, NASA will continue with the planning and development of the additional vehicles and systems required for lunar exploration. As a roadmap for future planning and design studies, NASA recently developed a set of DRMs associated with progressive growth of the lunar exploration capability over time. In order of time horizon and increasingly mature technology, DRMs 1 through 5 include:

- DRM 1 : Lunar Sortie Crew

  This mission lands anywhere on the Moon, uses only on-board consumables, and leaves within ~1 week. This mission enables exploration of high-interest science sites, scouting of Lunar Outpost locations, technology development objectives, and the capability to perform EVAs. This is the reference mission illustrated in figure 2-1.

- DRM 2 : Uncrewed Cargo Lander

  Used to support an Outpost, help build one, or preposition assets for a subsequent Sortie Lander, this uncrewed mission lands anywhere on the Moon, and has enough resources to sustain itself until a component of the Lunar Surface Systems takes over.

- DRM 3 : Visiting Lunar Outpost Expedition

  Analogous to an assembly flight to ISS, this mission lands at the site of a complete Outpost or one under construction, and allows crew members to extend their stay by using assets of the Outpost rather than only what is carried onboard their Lander.

- DRM 4 : Resident Lunar Outpost Expedition

  Realizing one of the goals of U.S. Space Policy, this mission allows a sustained human presence on the surface of the Moon, since it follows a single crew of four to the surface, transitions them to a habitat at an Outpost, and gets them back to Earth after transitioning over to a replacement crew.

- DRM 5 : Remote Outpost DRM

  This mission is separated in function from the other DRMs by focusing only on those Lunar Surface Systems that need to operate without human intervention, either because humans are not present to operate them, or the task is more easily performed in an autonomous or automatic manner.

The engineering and technical challenges associated with establishing a lunar outpost are formidable. Requirements to sustain human life and support useful activities will mean the development of new technologies and new machines to operate in a harsh and alien environment. NASA is just beginning to quantify the requirements for a lunar outpost and identify the types of equipment that will be necessary for extended lunar exploration.

A top-level set of Outpost requirements include:

- Habitation systems that will support a crew of 4 for 180 days on the lunar surface.
- Demonstrated ability to produce in-situ-based oxygen from lunar soil at a minimum rate of 1 ton per year.
- Unpressurized rovers that can be operated autonomously or by the crew.
- Pressurized roving systems that can travel for hundreds of kilometers from the Outpost.
- Power production of at least 35 kW of net power and storage for crewed eclipse periods.
- Surface-based laboratory systems and instruments to meet science objectives.
- Sufficient functional redundancy to ensure safety and mission success.

From these requirements, new key technologies will be needed (and are already being developed). Unlike the Apollo lunar lander, which used toxic hypergolic fuels, new propulsion technology and nontoxic fuels will be required for long-term lunar operations. Solar energy will be a primary power source on the lunar surface, and more efficient methods of producing (solar cells and films) and storing this energy (batteries and regenerative fuel cells) will be required. Procedures and devices (advanced filters and air purification systems) will need to be developed to deal with lunar dust contamination of mechanical systems, airlock seals, and human lungs. An assortment of machines will need to be designed, tested, evaluated, and redesigned to excavate, transport, and process lunar soil (and perhaps ice) for the production of oxygen, water, and fuel. New communication systems will be required using lunar orbiting satellites and/or ground relay stations to support voice and data transmission, and allow Global Positioning Satellite-style navigation and emergency-location on the lunar surface. Radiation protection and medical countermeasures for humans (both in transit and on the lunar surface) will take on a new research priority. Enhanced plant growth and food production in lunar soil and reduced gravity will be studied (crews can simply not carry all of the pre-processed food necessary for extended exploration). A spectrum of habitat designs, hard-shell versus inflatable, must be evaluated and improved (prototype modules are already being tested in Antarctica), as a precursor to using indigenous construction materials (e.g., lunar soil-based cement and blocks). And all of these systems and techniques require international operability to be negotiated with anticipated international partners.

These are only a few of the exploration building blocks necessary for a sustained human presence on the Moon and to develop the experience and technologies necessary for exploration of Mars and beyond. Clearly, the vehicles and propulsion and life-support systems developed for lunar exploration will not take humans to Mars, but they will serve as the necessary stepping stones to new science and technology that will permit humans access to their solar system. Some of the key lunar exploration technologies mentioned above will have direct applications for deep space exploration, and many of the lunar hardware designs and processes will be used as part of the initial exploration of Mars. Figure 3-3 shows an artist’s concepts of Mars exploration hardware with a clear heritage of systems that NASA is designing and building today.

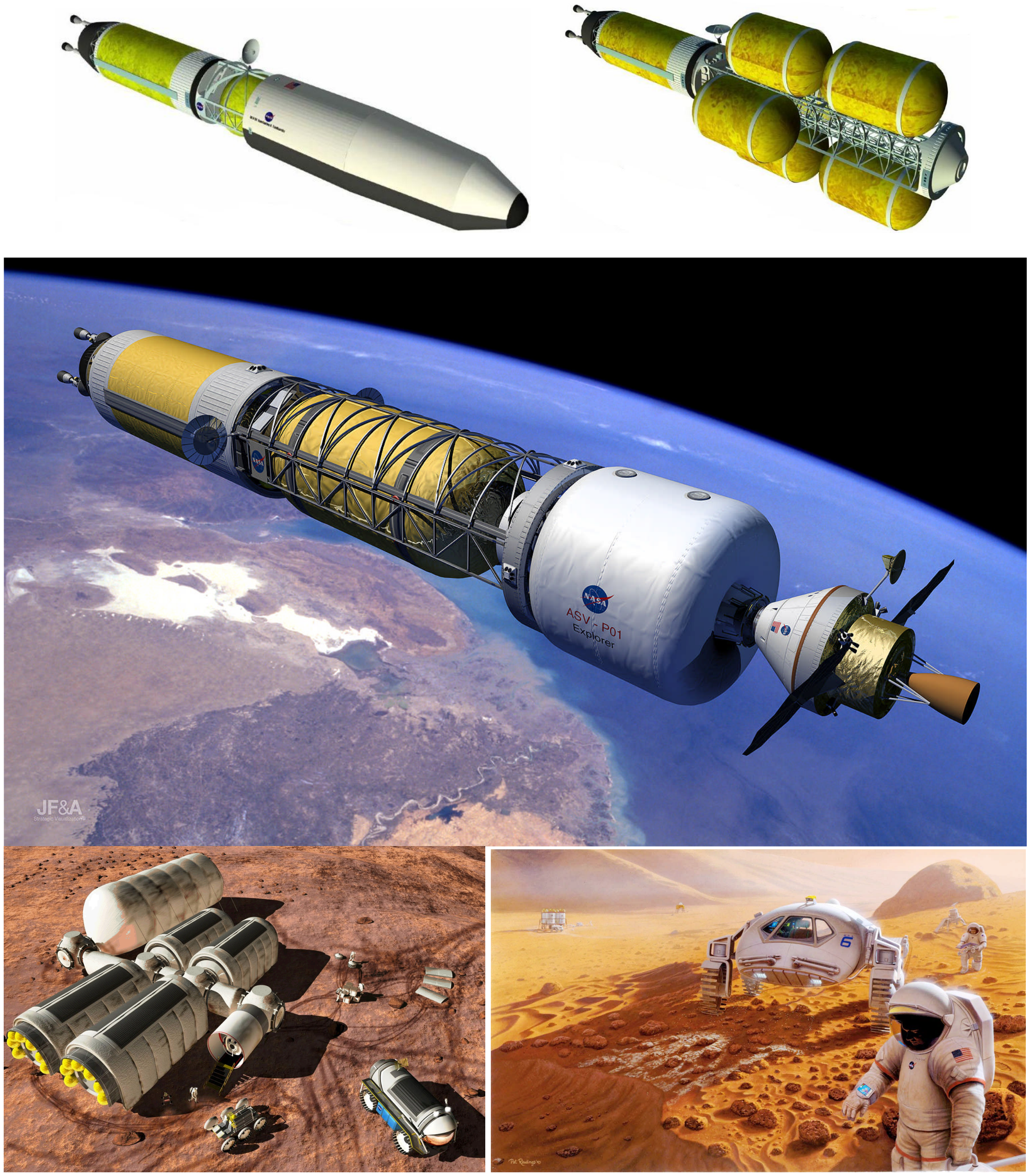


Figure 3-3. Artist's concept of future Mars exploration activities.

3.1 Summary

As the long-term objectives of U.S. space exploration evolve, the near-term goals remain the same: to develop the flight systems and ground infrastructure required to enable continued access to space and to enable future crewed mission to the ISS, Moon, Mars, and beyond. The program is evolving within this structure of organization, requirements, and funding as its foundation.

The Constellation Program is a robust system, based on the best of NASA's heritage while incorporating the latest advanced technology and processes, and it is designed to evolve as a safe and cost-effective infrastructure that will allow America to maintain and enhance its leadership in space exploration, technical innovation, and scientific discovery in the world community of the 21st century.

The Constellation Program is nearing completion of its preliminary design phase, beginning its flight test program, and undertaking critical design and manufacturing operations to support missions to the International Space Station in 2015, and human lunar exploration flights in 2020.

4.0 Appendices

Appendix A: Frequently Asked Questions about the Constellation Program

1. ***Question: With regard to the gap in U.S. crew launch capability between the end of Space Shuttle operations in 2010 and the beginning of Orion/Ares flights in 2015, what are the issues and options for maintaining a U.S. human presence in space and continuing to support research activities on the ISS?***

The current plan is to rely on the Russian government to ferry U.S. personnel and equipment from the Baikonur spaceport in central Kazakhstan to the ISS using the Russian Soyuz rocket and space capsule. The Soyuz capsule has delivered and returned 15 crews from the ISS since it began taxi operations to the station in 2000. Following the Space Shuttle *Columbia* accident in 2003, the Soyuz provided the only crew access to the ISS for almost 2-1/2 years until the Space Shuttle returned to flight. In addition to providing crew transportation, the Soyuz capsule also serves as an emergency crew return vehicle, or lifeboat, while it is docked at the ISS for approximately 6-month intervals. The Soyuz rocket also launches the Russian Progress cargo vehicle, which has made 30 resupply flights to the ISS to deliver equipment, fuel, water, and food to the orbital laboratory, and provide a regular trash-removal service. In the absence of Space Shuttle visits, periodic firings of the engines of docked Soyuz and Progress spacecraft are used to maintain the orbital altitude of the ISS. The photo below shows the Soyuz rocket and capsule for the ISS Expedition 15 crew being rolled out to the Baikonur launch pad in April 2007.

Figure A-1. Russian Soyuz rocket rollout.

Under current law, the United States is forbidden from purchasing space technology from Russia by the Iran-North Korea-Syria Non-Proliferation Act of 2000. Congress provided a waiver to this ban in 2005 to allow NASA to enter into a $719 million contract with Russia for use of the Soyuz through 2011. The waiver authority was extended until July 1, 2016, in H.R. 2638, The Consolidated Security, Disaster Assistance, and Continuing Appropriations Act of 2009. This bill was passed by the House and Senate and signed by the President on September 30, 2008. Roscosmos, the Russian national space agency, has stated that they require a 3-year advance notification to manufacture and certify the

Soyuz spacecraft necessary for a new contract, which means that a waiver decision for a regular (non-accelerated) contract was needed by the end of 2008.

A number of organizations, including NASA, have expressed concern about relying solely on the Russian government to provide launch and transportation services for U.S. crews during the gap in U.S. spaceflight capability between the end of Space Shuttle flights and the beginning of operational Orion/Ares flights. This situation has received particular attention since the escalation in tensions between the U.S. and Russia following the deployment of Russian troops in the contested Georgian territories in August 2008.[12] In an analyses of the potential impact of the Iran Non-Proliferation Act on the Space Station Program prepared by the Congressional Research Service in 2005, it was noted that “even if a method is found to allow NASA to pay Russia, that is only one step in ensuring U.S. crew access to the ISS. An agreement still would have to be negotiated with Russia on its terms and conditions. Russia could charge too high a price, or set operational procedures with which NASA disagrees, complicating such negotiations. The political relationship between the two countries also could change. The only way to ensure that U.S. astronauts can use ISS is to have a U.S. spacecraft that can make the journey.” [13]

In addition to the political issues surrounding Soyuz use, there is also a concern regarding the design and operational record of the vehicle. While the Soyuz rocket and capsule have an excellent overall safety record during their ISS service so far, there have been repeated problems during crew reentry and landing. During three of the last 15 Soyuz landings, the vehicle and crew have been unexpectedly subjected to a steep, high-gravity-force reentry profile known as a ballistic reentry (Soyuz TMA-1 in May 2003, TMA-10 in October 2007, and TMA-11 in April 2008).[14, 15, 16] During these events, the crew was subjected to gravitation forces between six and eight times the normal 1-g force experienced in daily activities on Earth’s surface, and the three capsules landed hundreds of miles off course in the rural areas of Kazakhstan. These reentry problems have been traced to various hardware and software malfunctions and, most recently, to the failure of the Soyuz crew capsule and propulsion module to properly separate prior to atmospheric entry.

Below are photos of the Soyuz crew return vehicle after undocking from the ISS and the crew capsule after landing in central Asia.

Figure A-2. Soyuz undocking and landing.

If new Soyuz crew transportation services beyond 2011 are not used, it is possible to close the U.S. flight gap from either or both ends of the gap – by extending Space Shuttle operations beyond 2010 and/or accelerating the development and Initial Operational Capability date of early 2015 for the Orion/Ares spacecraft. The most significant closure could be obtained by extending the Space Shuttle Program, with limited acceleration of Orion/Ares availability possible due to the structure of the flight test program and the contractual commitments already established with multiple tiers of hardware and software developers.

A preliminary schedule acceleration study has been conducted by the Constellation Program. An acceleration of the initial operational capability date by 1 year (from late 2014 to late 2013) is possible, assuming that funding is provided and the acceleration process is begun in early 2009. Acceleration of the first crewed launch to earlier than late 2013 is not possible due primarily to serial vehicle qualification testing and long lead time vehicle procurements (e.g., over 50% of vehicle components would need to be in the procurement pipeline before the completion of the Orion Preliminary Design Review, which is not allowable by any reasonable project management standards).

It must be noted, also, that extending Shuttle operations without additional funding will cause significant delays to the lunar return portions of the Constellation Program (e.g., Ares V, Earth Departure Stage, and Altair lunar lander development). The Constellation Program is currently relying on the planned Space Shuttle retirement in 2010 to provide budget reserves and across-the-board funding increases for all areas of the Constellation Program (see figure C-1). Successful use of both options requires optimization and depends critically on timely implementation decisions and additional funding commitments to NASA.

It is not clear that Soyuz service to the ISS could (or should) be entirely eliminated. Extended Shuttle flights beyond 2010 can deliver and return ISS crews and transport large amounts of additional equipment and supplies to the ISS; however, the Shuttle cannot be used as a lifeboat attached to the ISS for 6-month intervals (unless substantial modifications are made to the Shuttle Orbiter vehicles). Additionally, a reduced launch rate (perhaps one or two Shuttle flights annually) may be necessary for extended operations, since the Space Shuttle Program has already begun to reduce the launch processing workforce at Kennedy Space Center and has begun termination of spare part resupply contracts which support the current Shuttle flight rate.

In August 2008, NASA Administrator Mike Griffin directed the agency to study what would be required to extend Space Shuttle operations beyond 2010.[17] A preliminary report is expected by the end of September 2008.

2. ***Can we make arrangements to use the Chinese crew launch vehicle to support the ISS during the gap?***

Probably not. While the People's Liberation Army of China has conducted three crewed launches since 2005, their current spaceflight capability must be considered to be still in the developmental (rather than operational) phase. Beyond the previously discussed drawbacks to U.S. reliance on a foreign government to provide spaceflight services, the near-term integration of ISS-compatible systems required (e.g., for rendezvous and docking, communication, electrical, and thermal system sharing, and orbital reboost of the ISS) would be extremely costly and time intensive, and would require a significant U.S. technological investment in upgrading and accelerating Chinese space technology.

3. ***Question: There has been discussion in the media regarding a Direct transportation architecture for returning to Moon, and some people argue that this Direct system is better than the Constellation architecture plan. What is the Direct system and why is it not being used?***

The Direct proposal is a theoretical set of launch vehicles derived more directly (hence the name) from the existing Space Shuttle transportation system, using the Shuttle SRBs as they exist today and the Shuttle external fuel tank with minimal modifications. These vehicles are also referred to as the Jupiter launch vehicles or the Direct 2.0 plan.[18] The Direct hardware commonality concept is shown below.

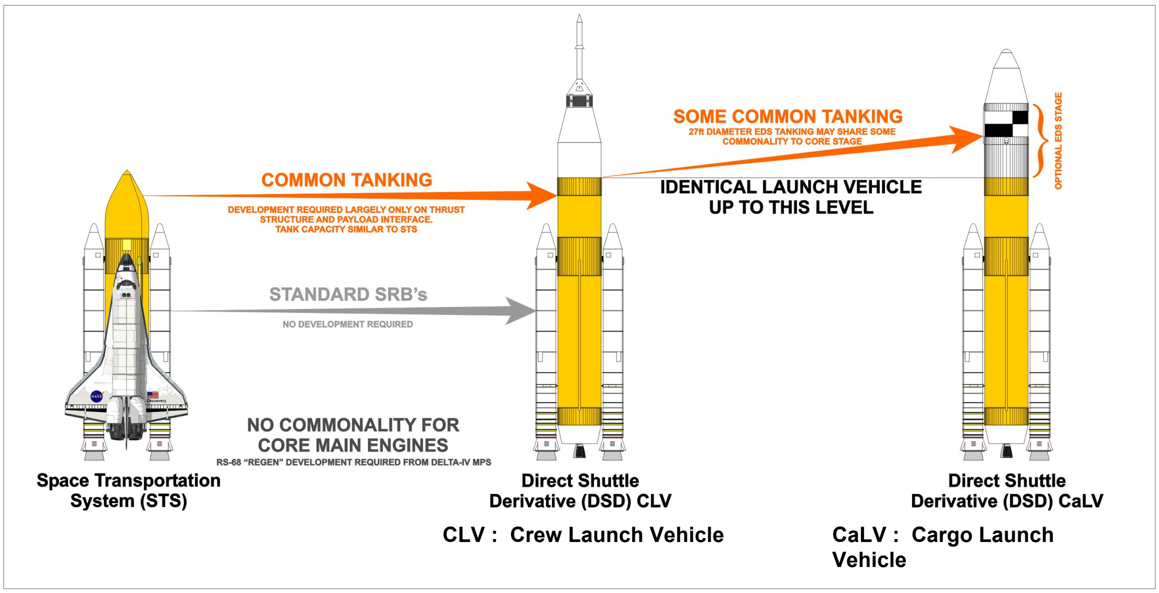


Figure A-3. Direct hardware commonality concept.

This concept (Direct 1.0) originated at NASA in the mid-1980s following the Space Shuttle *Challenger* accident; however, lacking the funds or national mandate to develop an alternate launch system, this concept never progressed beyond the proposal stage. An updated version of the Direct concept (Direct 2.0) was proposed in 2007 by a group of independent aerospace companies as an alternative to the Constellation Ares I and Ares-V designs. The primary advantages of the Direct approach would be reduced development cost for the SRBs and fuel tanks, including less retooling costs associated with manufacturing the new tanks (which would be the same diameter as the Space Shuttle tank, rather than the new, larger diameter tank planned for Ares-V) and less modifications to the ground processing facilities that are already used for the Shuttle tank. Direct advocates maintain that it is not necessary to design launch vehicles with as many new design features as are proposed in the Ares design.

In general, the reasons for not using Direct 2.0 are that the crew launch vehicle is over-powered for its primary purpose (putting crews into low Earth orbit) and that the large liquid fuel tank and engine (an RS-68 engine that would now have to be human-rated) with side-mounted solid rockets is a less safe configuration for crew launches than the single solid rocket and stacked upper stage liquid fuel engine used for Ares I. Also, by the time that the updated Direct proposal was submitted in mid-2007, NASA was already two years into development of the Ares architecture (including launch site modifications), and the costs associated with a design restart were prohibitive.

David King, the director of NASA's Marshall Space Flight Center (where the Direct concept originated in 1986), recently addressed the new Direct 2.0 proposal in an editorial for *The Huntsville (Alabama) Times*[19] and summarized by saying: *"Direct 2.0 falls significantly short of the lunar lander performance requirement for exploration missions as specifically outlined in Constellation Program ground rules. The concept also overshoots the requirements for early missions to the International Space Station in the coming decade. These shortcomings would necessitate rushed development of a more expensive launch system with too little capability in the long run, and would actually increase the gap between Space Shuttle retirement and development of a new vehicle. Even more importantly, the Ares approach offers a much greater margin of crew safety - paramount to every mission NASA puts into space."*

4. ***Question: Was the Direct concept considered for use in the Constellation architecture? If so, what are some specific reasons that the Direct concept was not chosen?***

Yes, NASA studied architecture options with vehicles closely derived from the Space Shuttle and other Expendable Launch Vehicles. Administrator Michael Griffin chartered the ESAS in May 2005, comprised of experts at NASA Headquarters and across the NASA field centers. All databases, expertise, and analytical models related to space systems development were applied to this critical task. Particular emphasis was placed on the family of launch vehicles that would be needed to support future Exploration goals. A large number of options were evaluated, including quantitative comparisons on the basis of important measures of merit such as development cost, recurring cost, funding profiles, safety, reliability, development risk, schedule risk, and other factors. The launch families considered included various Shuttle-derived options, Evolved Expendable Launch Vehicle (EELV)-derived options and mixes of the two, and outside experts were brought in to assess the ESAS results.

The ESAS concluded that NASA should adopt and pursue a Shuttle-derived architecture as the next-generation launch system for exploration missions due to significant advantages with respect to safety, reliability, and cost. The extensive flight and test databases of currently flying hardware/software give a very strong technical and safety foundation with clearly defined and understood elements to anchor next-generation vehicles and minimize development costs and risks to flight crew. And the Ares architecture does make extensive use of previously derived technology and experience. The Shuttle solid rocket motors, the resized ET, the non-human-rated RS-68 engine (for the Ares V Cargo Launch Vehicle), much of the avionics and other flight subsystems, and the upgraded human-rated J-2X engine are all adapted from previously flown, proven technology.

Several of the Shuttle-derived concepts that were considered during ESAS, and in other studies, were similar to the Jupiter system identified as part of the Direct proposal. However, using current ground rules and assumptions, and using validated NASA and industry design and analysis tools, NASA has determined that the Direct proposal is unlikely to achieve its claims of improved performance, safety, and development costs when compared to the Ares I and Ares V approach. In addition, the limited data available in the online Direct proposal do not support the claims of increased safety. Also, analysis shows that the Direct proposal would cost more than the Ares family in the near-term and also on a recurring launch basis. Finally, the Direct proposal would take longer to develop when compared to the Ares vehicles when factoring in the extensive core-stage development effort and the associated acquisitions.

Since completion of the ESAS, NASA has continued to improve the baseline architecture to significantly lower life cycle costs of the Ares vehicles. NASA's analysis confirms that the Ares I and V vehicles enable the lowest cost and safest launch architecture which meets the Agency's requirements for support of the ISS, as well as lunar and Mars exploration. Several improvements have been made to the Ares ESAS baseline (such as the decisions to use the J-2X for both the Ares 1 and the Ares V Upper Stage engine and the RS-68 instead of the Space Shuttle Main Engines for the Ares V core engine) which reduced life cycle costs by several billions of dollars.

DIRECT claims that schedule improvements would be achieved by leveraging existing Shuttle Reusable Solid Rocket Motors and RS-68 engines and implies that only modest modifications to the Shuttle's ET would be necessary. The Jupiter's Shuttle ET-based core stage in fact would require a major development effort, which in turn would drive a longer schedule when compared to the current Ares approach. DIRECT claims requirements to strengthen ET sidewall and interstage structures on the Jupiter common core are achieved by milling less material during manufacture. NASA has extensively examined such approaches over the past 20 years and concluded that this effort incurs significant expense and development schedule risk and would result in marginally applicable Shuttle ET heritage.

The Jupiter common core requires new design efforts for the main propulsion system, new thrust structure, new avionics, new forward liquid oxygen tank structure and a new payload shroud, substantial intertank/liquid hydrogen tank redesign and aft Y-ring interfacing and a completely new stack integration effort. In addition, recurring ET manufacturing is costly and labor intensive compared with the lower cost, all friction-stir-welded approach being used on the Ares vehicles. Also, the Jupiter core stage engine, the RS-68, would be required to be human rated. Though feasible, it would require a significant development effort and an extensive engine test program, again increasing development schedules.

The Direct proposal is also taking on development of a new, Saturn V S-II class EDS for lunar capable missions. Direct proposes to develop low boil-off rate technology and integrate it into the EDS tanks. NASA has studied this type of approach extensively in the past. This development effort would require significant near-term technology maturation before full-scale development can proceed, again lengthening the Jupiter's EDS development schedule due to use of low Technology Readiness Level hardware. Per-flight costs for Orion missions also favor the Ares approach. The Ares I vehicle will have less cost per flight compared with the Jupiter 120 heavy lift counterpart: one five-segment Reusable Solid Rocket Motor versus two four-segment boosters and an upper stage with one J-2X versus a core stage with two or three RS-68s.

NASA’s assessment of the Jupiter 232, calibrated to Ares and Constellation ground rules and assumptions, and using Agency and industry tools and design standards, found that the delivered gross lunar lander mass falls ~ 50 percent below the reported value for an Earth Orbit Rendezvous-Lunar Orbit Rendezvous mission. This assumes no on-orbit cryogenic tanking, which Direct requires (on-orbit cryo tanking is a highly complex, unproven, and operationally risky proposition for this mission class). Even with on-orbit tanking, Direct falls short by more than 25 percent. This approach cannot meet NASA’s performance requirements.

A more detailed summary of the performance analysis of the Direct 2.0 Space Exploration Architecture which was conducted by the NASA Marshall Space Flight Center in 2007 can be found at:
http://www.nasa.gov/pdf/257003main_NASA%20Performance%20Assessment%20of%20(DIRECT%202)%20Compiled.0702.pdf

5. ***Question: What is the thrust oscillation problem with the Ares I crew launch vehicle, and how is NASA addressing the problem?***

Thrust oscillation, also called resonant burning, is a phenomenon characterized by increased acceleration pulses that may be felt during the latter stages of first-stage powered flight of solid rocket motors. Depending on the amplitude of these pulses, the impact on the vehicle structure and astronauts may be significant.

Thrust oscillation is a characteristic of all solid rocket motors including the first stage of the Ares I launch vehicle, and it is not an unusual problem to encounter (or mitigate) during the development program of a new rocket configuration. Vortices, created inside the solid rocket motor by the burning propellant or other flow disturbances, can coincide, or tune, with the acoustic modes of the motor combustion chamber, generating longitudinal forces. These longitudinal forces may increase the loads experienced by the Ares I during flight, and may exceed allowable loads on various portions of the vehicle and allowable forces on the astronaut crew. "It is a well and long understood phenomenon in the launch industry," said George Torres, a spokesman for ATK, the prime contractor for the Ares I first stage. "Many other launch vehicles at this stage of development have had to deal with this issue and have dealt with it as a normal part of the development process." [20]

In November 2007, NASA chartered the Thrust Oscillation Focus Team to precisely define the frequency spectrum and oscillation amplitudes that the five-segment motor is expected to produce. These analyses are being accomplished using a combination of available ground test motor data as well as early Shuttle solid rocket motor flight data. Efforts are underway to update the existing data set by adding instrumentation on several upcoming Shuttle flights. In parallel, the team is evaluating vehicle structural assessments to provide additional vibration isolation to critical launch vehicle systems and uncouple the vehicle’s natural frequency from motor-induced loads. Since upper-stage elements and the command/service module are not yet fully designed, this is an excellent time to factor in thrust oscillation mitigation if it is required. The team’s analysis has already led to several mitigation strategies, including the removal of a significant amount of conservatism from within existing models, correlating to significantly lower loads by a factor of almost two. Additionally, the team was able to remove the first longitudinal mode as an issue – the remaining effects are now in a narrow, manageable region in the 12Hz frequency range. NASA will conduct additional analysis coupled with upcoming flight tests on the Shuttle and Ares 1-X (planned for April 2009) to better characterize this phenomenon, which may further reduce loads. Prime candidates for mitigating the remaining thrust oscillation include installing mechanical vibration isolation devices (shock absorbers) between the First Stage and Upper Stage of the vehicle, using a tuned mass absorber (a mass suspended by springs within the Ares structure designed to absorb and dissipate a specific harmonic vibration), and the addition of vibration isolation devices to the crew seats in Orion.

An overview presentation of the Thrust Oscillation Focus Team, including various mitigation options, is available at: http://www.nasa.gov/pdf/221186main_toft_checkpoint_report.pdf

6. ***How does the Constellation Lunar Exploration Program compare to the Apollo Program of the 1960s in terms of cost and schedule. If Apollo managed to land a crew on the Moon in just 8 years (the time between President Kennedy's lunar landing commitment in 1961 and the Apollo 11 landing in 1969), shouldn't we be able to do it in less time today?***

Actually, despite different work environments and different funding profiles, the two programs are comparable. Based on extensive NASA and military engineering experience, 6 to 7 years is a fairly typical unconstrained (i.e., not limited by engineering talent availability, production capability, or funding) development cycle for a new vehicle development, taking into account the finite number of sequential activities that need to occur in the design, development, test, and evaluation of any sufficiently complex vehicle. In retrospect, this is applicable to Apollo when the delay following the Apollo 1 accident is considered, and it is applicable to the original schedule and cost estimates for the Orion/Ares I vehicle. It is also applicable to projected development for the Ares V heavy lift vehicle and the Altair lunar lander. However, due to the extended funding profile imposed on the Constellation Program, the Orion/Ares I and the Ares V/Altair projects are being developed somewhat serially rather than in complete parallel development as was the case with all Apollo components.

The Apollo budget to achieve the Apollo 11 landing, adjusted to Fiscal Year (FY) 2008 dollars, was about $150 billion to 160 billion. There is some uncertainty because the existing historical data does not separate production for follow-on flights, requiring an educated guess at how exactly to separate the funding stream. Constellation will take about $65 to $75 billion in FY 2008 dollars, or roughly one-half of Apollo. Allowing for the lower total cost, Constellation's funding profile is about half the rate of Apollo, and about twice as long. Figure A-4 shows Apollo and Constellation funding profiles by year of effort in FY 2008 dollars. The Apollo line uses $160 billion, and the Constellation line uses $65 billion.

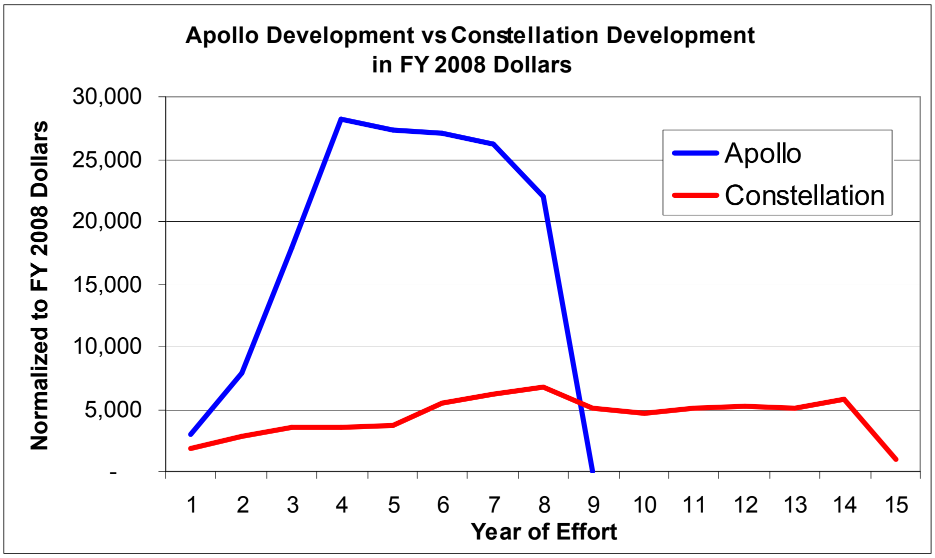


Figure A-4. Apollo vs. Constellation development in FY 2008 dollars.

If the funding required for Constellation's development were phased like Apollo, NASA could begin development of the Ares V Cargo Launch Vehicle, Altair Lunar Lander, and associated ground support facilities now, in parallel with the Ares I Crew Launch Vehicle and Orion Crew Exploration Vehicle, rather than the somewhat serial development that is imposed by funding constraints. (In reality, there is as much concurrent engineering development as possible, such as the J-2X engine which will be used on both Ares I and Ares V, and the solid rocket boosters which are common to both vehicles.)

It is interesting to note, however, that there are some systemic changes since the 1960s, beyond the 'space race' motivation, that suggest that Constellation cannot operate as efficiently as Apollo. These are summarized below. Even despite these changes, the experience of Apollo, Shuttle, and Station, and use of heritage-derived hardware from Shuttle will allow Constellation development at about ½ the cost of Apollo.

- Workforce Commitment: There are anecdotes that the Apollo workforce put in a tremendous amount of unrecorded overtime. This is unlikely to occur today and, in some, instances it would be illegal.

- Lack of Recent Crewed Vehicle Development: Apollo was developed immediately following the Mercury and Gemini Programs, so the workforce had tremendous fresh experience developing new crewed flight vehicles. For Constellation, the last similar systems development experiences are Shuttle, which ended major development in the early 1980s, and ISS, which ended development in the late 1990s. Constellation has had to effectively re-learn the art of systems development for crewed flight vehicles.

- Increased Ancillary Burdens: The regulatory environment at federal, state, and local levels has tightened considerably since the 1960s. Costs to comply with environmental, workplace safety, labor, financial reporting, and other regulations are significantly higher than for Apollo. NASA's internal requirements, standards, and practices for program management, safety, and other ancillary functions have increased, particularly after each of the three losses of crew. Staffing and costs to comply with Congressional auditing and reporting requirements also appear to have increased. The merits of these process enhancements notwithstanding, covering these increased burdens has come at the expense of rapid core development.

- Long-Term Goals: Constellation is arguably more ambitious, pursuing improved capability (mass, crew size, productive time at destination) and better forward extensibility than Apollo (forming the basis for a sustained, evolving human presence in space). More ambitious content will likely cost more in time and/or money.

- Organizational Inertia: Constellation will be challenged to adopt new ways of doing business that save time, labor, and cost simply because of the large organization structure and heritage of the NASA organization at 50 years old. NASA during the Apollo era was a "clean sheet" agency. There was little bureaucratic inertia and few established ways of doing things. While this meant that Apollo had to invent organizational and operational practices, it also meant that Apollo could choose promising ways unconstrained by existing practice.

- More Developments: Compared to Apollo, Constellation is developing one more engine, one more launch vehicle stage, and ground processing capability for one more launch vehicle. However, Constellation has the advantage of hardware heritage. It's not clear how the combination of these differences net out in cost and schedule. Although the Constellation engines, stages, and ground operations have considerable heritage, significant development is still required. Constellation's program management, systems engineering, and integration functions have more "parts" to deal with relative to Apollo (see the summary table below). Beyond the initial goal of limited human exploration of the Moon, Constellation must also plan for the eventual development and integration of many new components for a sustained lunar base, and conduct extensive advanced planning to support exploration of Mars and beyond.

Apollo Developments	Constellation Developments
Crew Module / Service Module	Orion Crew Module / Service Module
Lunar Excursion Module	Altair lunar lander
F-1 engine	RS-68 upgraded engine
J-2 engine	J-2X engine
	5-segment Solid Rocket Boosters
1st, 2nd, 3rd Saturn stages	Ares V core, Ares V EDS, Ares I Upper Stage
	Ares I booster stage
Ground ops for Saturn V stack	Ground ops for Ares V stack
	Ground ops for Ares I stack
	Lunar Surface Systems

Appendix B: Space Commercialization and Education & Outreach

Space Commercialization

The International Space Station is scheduled for completion of Shuttle-supported assembly operations in 2010. The number of Shuttle flights required to complete the Station was the prime factor that determined the Shuttle retirement date. The completed ISS will contain large laboratory modules from the United States, Russia, Europe, and Japan, as well as a fully operational solar power system and a six-person permanent crew.

NASA estimates more than 8000 kg of internal cargo and 5000 kg of external cargo will need to be delivered annually during the fully assembled phase of ISS, and the agency is working to develop a commercial space market that will help transport equipment and supplies to the ISS during the gap between retirement of the Space Shuttle and the fully operational Constellation vehicles (2010-2015).

The Commercial Crew and Cargo Program Office is leading a first-ever commercial project designed to entice private firms to invest in space exploration technology. The Commercial Orbital Transportation Services (COTS) project provides milestone-based seed money to develop and demonstrate unscrewed, Earth-to-orbit launch and rendezvous capabilities. COTS is the first NASA project to allow private companies to completely own and profit from the products developed in partnership with NASA.

> ***"If we are to make the expansion and development of the space frontier an integral part of what it is that human societies do, then these activities must, as quickly as possible, assume an economic dimension as well. Government-directed space activity must become a lesser rather than a greater part of what humans do in space.***
>
> ***"To this end, it is up to us at NASA to use the challenge of the Vision for Space Exploration to foster commercial opportunities which are inherent to this exciting endeavor. Our strategy to implement the Vision must, and we believe does, have the potential to open a genuine and sustainable era of space commercialization."***
>
> - NASA Administrator Mike Griffin (October 2005)

The NASA Authorization Act of 2005 provided NASA approximately $500 million to award to selected companies for meeting financial and technical benchmarks. Space Exploration Technologies (SpaceX) of El Segunda, CA, and Orbital Sciences Corporation of Dulles, VA, the two remaining COTS companies, have each earned approximately $200 million each during performance reviews of their evolving orbital capabilities, and their continued success could potentially open new markets and pave the way for other companies to follow suit.

More information on the NASA Commercial Crew and Cargo Program Office can be found at http://www.nasa.gov/directorates/esmd/ccc/.

NASA is also working to maximize space exploration capabilities through its Innovative Partners Program (IPP), which leverages technology for its missions through investments and partnerships with industry, academia, government agencies, and national laboratories. Three IPP strategies, Technology Infusion, Innovation Incubator, and Partnership Development, engage private citizens and companies in aerospace technology development, bring fresh ideas into NASA, help mature emerging technologies, and promote the growth of a competitive private space industry.

The Technology Infusion strategy offers small businesses the opportunity to participate in NASA research and development with an initial cash limit of $100K (for the first 6 months), and a follow-on limit of $600K (for the next 24 months). An IPP Partnership Seed Fund provides bridge funding for larger, cost-shared, joint-development efforts which continue to show promising results.

The Innovation Incubator strategy hosts the Centennial Challenges, which uses competitions and cash prizes for the most innovative solutions to different design challenges. Competitors range from student groups to individual inventors to private companies. Some of the Centennial Challenges have direct application to Constellation Program design activities. For example, Maine engineer Peter Homer collected the $200,000 Astronaut Glove Centennial Challenge prize in 2007 for an innovative design that is being studied for further application by NASA and private industry. NASA is also interested in the work by Armadillo Aerospace Company of Mesquite, TX, on vertical take-off and landing rockets and new fuel research work done as part of a lunar lander design competition. Additional Centennial Challenges underway include designs for a lunar regolith (soil) excavator, equipment, and processes for extraction of oxygen from lunar soil, and demonstration of wireless power beaming as a method for vehicles to travel without the need to carry onboard batteries or other power sources (e.g., during lunar night or crater shadow operations). Figure B-1 shows some private projects involved with the NASA Centennial Challenges.

Figure B-1. Left-to-right: Armadillo Aerospace's Pixel lander vehicle hovering in tethered flight, Peter Homer demonstrating his winning astronaut glove design, and a prototype lunar regolith excavator vehicle being demonstrated at 2008 Regolith Excavation Challenge.

Companies that require testing their technology in a microgravity environment can use the commercial jets in NASA's Facilitated Access to the Space Environment for Technology Development and Training project. The Zero-G Corporation of Las Vegas, NV, has a contract with NASA to provide parabolic flights for Challenge experiments requiring only short durations of microgravity. More information on the NASA Centennial Challenges is available at http://centennialchallenges.nasa.gov/.

NASA's Partnership Development strategy identifies and facilitates opportunities among companies, schools, and individuals to co-develop technology alternatives for NASA mission directorates in response to specific technology needs or new mission requirements. The IPP typically facilitates over 200 new partnerships with the private and other external sectors each year. More detailed information on current partnerships and other IPP activities is available at http://ipp.nasa.gov/index.htm.

Education & Outreach

> ***"The greatest contribution that NASA makes in educating the next generation of Americans is providing worthy endeavors for which students will be inspired to study difficult subjects like math, science, and engineering because they too share the dream of exploring the cosmos. These students are our future workforce and our education investment portfolio is directly linked to our overall workforce strategy."***
>
> - NASA Administrator Michael Griffin (Statement to the House Science Committee, February 2006).

NASA has a long commitment to promoting interest and educational opportunities in science- and engineering-related fields of study. Few other government agencies have such a dramatic and sustained need for a well-educated and highly skilled workforce. To help ensure NASA's future workforce, as well as to encourage general science and mathematics interest in students at all grade levels, the NASA Strategic Plan articulates three major education goals, which will continue to support U.S. innovation and competitiveness now and in the future:

- Strengthen NASA and the Nation's future workforce – NASA will identify and develop the critical skills and capabilities needed to achieve the U.S. Space Exploration Policy. To help meet this demand, NASA will continue contributing to the development of the Nation's science, technology, engineering and mathematics (STEM) workforce of the future through a diverse portfolio of education initiatives that target America's students at all levels, including those in traditionally underserved and underrepresented communities.

- Attract and retain students in STEM disciplines – To compete effectively for the minds, imaginations, and career ambitions of America's young people, NASA will focus on engaging and retaining students in STEM education programs to encourage their pursuit of educational disciplines critical to NASA's future engineering, scientific, and technical missions.

- Engage Americans in NASA's mission – NASA will build strategic partnerships and linkages between STEM formal and informal education providers. Through hands-on, interactive, educational activities, NASA will engage students, educators, families, the general public, and all Agency stakeholders to increase Americans' science and technology literacy.

These goals are in effect across all of NASA, and the Constellation Program is no exception. To that end, NASA's Exploration Systems Mission Directorate (ESMD), the lead management organization of the Constellation Program, funds and develops a number of education initiatives to engage students in the science and engineering aspects of human space exploration. To aid educators who seek to use NASA resources as part of their classroom curriculum, ESMD provides a number of customized programs and resource materials that are available to public and private educational organizations across the country. A selection of these programs is described below.

College-Level Programs

Space Grant Internships/Senior Design Projects: ESMD offers Space Grant consortia funding to involve students (graduate and undergraduate) in hands-on training relevant to science and engineering projects. The ESMD Higher Education Internship Grants find and place students in summer or school-year internships in industry or at NASA centers, where they are able to work side-by-side with scientists and engineers and are involved with real-world application of their academic skills.

The second part of this project provides funds to integrate ESMD mission challenges into university senior engineering design courses. These funds are used to support student senior engineering design projects (i.e., to buy materials, build prototypes, etc.) or to bring in subject matter experts to consult with the class. Systems engineering experience is a key aspect of the overall program and to emphasize this, ESMD has offered cash prizes and travel to teams that write winning papers describing the role that systems engineering played in their senior design project.

ESMD Faculty Fellows: This project funds five faculty annually, each of whom is paired with two NASA centers to help gather senior design project ideas and internship opportunities relative to space exploration in support of the ESMD Space Grant Program. In addition, the faculty members learn about other ESMD education programs and help the education offices at their sponsor centers develop new programs.

University Student Launch Initiative: This annual competition challenges university-level students to design, build, and fly a reusable rocket with scientific payload to an altitude of one mile. The project engages students in scientific research and real-world engineering processes with NASA engineers. University Student Launch Initiative requires a NASA review of the teams' preliminary and critical designs and postflight performance analysis, basically identical to the real-world process used at NASA. The reviews are conducted by panels of scientists and engineers from NASA and from NASA contactors.

Figure B-2. University Student Launch Initiative teams during launch and recovery operations.

Spaceward Bound: An educational program to engage students and teachers in the exploration of remote and extreme environments on Earth as analogs for human exploration of the Moon and Mars. Working with undergraduate and graduate students in STEM and in-service STEM K-12 teachers and education faculty, this program uses field expeditions and Mars environment simulations to study the science and engineering required for human exploration beyond the Earth.

Systems Engineering Educational Discovery: NASA collaborates with the University of Texas to host a national workshop on systems engineering education and curriculum dissemination to engineering faculty engaged in undergraduate education. Additionally, three engineering students who complete this course will intern at JSC in Systems Engineering jobs. Systems Engineering Educational Discovery also provides undergraduate seniors and their faculty mentors from across the nation the opportunity to fly their projects in microgravity on NASA research aircraft.

ESMD Senior Design Course: An annual workshop for 10 faculty members on the subject of developing a Senior Design course at their schools based on one of the four ESMD-related areas: Propulsion, Lunar and Space Sciences, Spacecraft, or Ground Operations.

Elementary and Secondary Education Programs

Engineering Design Challenge: Lunar Plant Growth Chamber. In anticipation of the need for research into lunar plant growth, NASA and the International Technology Education Association (ITEA) sponsor this classroom design activity which allows elementary, middle, and high school students to design, build, and evaluate lunar plant growth chambers. Teams can request cinnamon basil seeds that have flown in space on the STS-118 Space Shuttle mission so that students can compare plants grown from both space-flown and Earth-based control seeds, and test the designs of their lunar plant growth chambers.

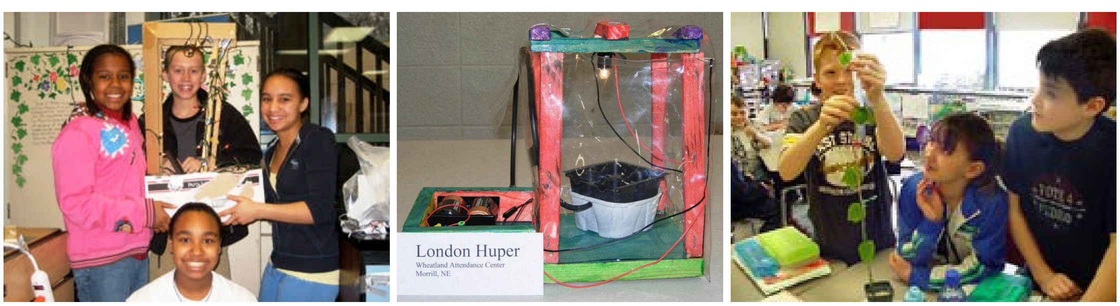


Figure B-3. Students working with the Lunar Plant Growth Chamber Program.

Human Exploration of Space: The ITEA is working with ESMD to create grade-appropriate classroom activities related to space exploration topics that require student teams to research a question or problem, break into teams to conduct specialized research, synthesize information, and develop recommendations and conclusions based on what they have learned. The ITEA showcases materials developed in this program through their online web-based network, providing a forum for educators to share strategies for implementing additional activities associated with lunar power production, space transportation, and space project management techniques.

NASA's Beginning Engineering Science and Technology Students: This middle school project provides a 3-week summer bridge program for students entering 9th grade in STEM Magnet Schools. These students study Fundamentals of Lunar Robotics, including the history of lunar exploration, motivations for past and future exploration, introduction to physical properties of the Moon, remote imaging and hands-on projects about lunar exploration.

21st Century Explorer: This project includes Web sites that deliver multimedia products and NASA exploration information; an after-school program targeting Hispanic communities to engage students, educators as well as the community; and development of educational packages that are ready for the 3rd – 5th grade classroom and which revolve around ESMD space exploration themes. This project also concentrates on the bilingual aspect of the material.

High School Mathematics Modules: This project infuses exploration content into a number of independent learning modules that are aligned with the national mathematics standards and the scope and sequence of the algebra-one curriculum.

Space Faring: The Radiation Challenge: This project instructs students about the dangers of radiation in space. The activities and videos deal with questions regarding "What is Radiation" (Space Radiation), "How does it affect humans" and "How will we protect from it" on long-duration space travel.

Lunar Nautics: This project is a compilation of hands-on activities hosted by Discovery Place museum. Students in grades 6-8 are asked to form their own aerospace company and embark on a mission regarding lunar exploration, a project which is ideal for after-school and outreach programs, workshops, and week-long camps. This project also works to inspire young people to consider careers in science, technology, engineering, and mathematics.

NASA Fit Explorer: Managed by NASA in partnership with the President's Council on Physical Fitness and Sports, this project is a scientific and physical approach to human health and fitness on Earth and in space. Students in grades 3-5 train like an astronaut by completing physical activities modeled after the real-life physical requirements of humans traveling in space, and gain an understanding of the science behind nutrition and physical fitness by studying how these factors relate to space exploration.

The Space Exploration Advanced Placement Project: This is a multi-center educational effort to develop, test, and release space-related support material to Advanced Placement educators nationally and internationally in calculus, physics, and chemistry.

The USA TODAY Collaboration: The national newspaper USA TODAY uses content provided by NASA to develop customized educational lessons from real-world articles appearing in USA TODAY and makes them available online to their network of educators. The collaboration also includes development of exploration-specific case studies for college students as well as a micro-Web site and an electronic newsletter.

Problem-Based Units for Physical Sciences: This project is based on a scenario for a lunar outpost located at the South Pole of the Moon. The Web-based module asks students to select a lunar-outpost site and a number of instructional activities are presented, including Rover Forces & Motion; Reduced-gravity Demonstrations; Inertial Balance; Rover Crater Peeking; and Orbital Mechanics. These activities are aligned with the National Science Standards, the National Council of Teachers of Mathematics Principles and Standards, the Technology Standards, and the Ohio state academic standards.

Rockets: An Educator's Guide with Activities in Science, Mathematics, and Technology: NASA is updating this very popular publication for teachers. The last edition was published in 1995 and this new edition will contain activities related to human exploration of the Moon and Mars.

Informal (non-classroom) Activities to Inspire and Engage Students and the Public:

A Field Trip to the Moon: Managed by NASA in conjunction with the American Museum of Natural History (AMNH), this project brings the U.S. Space Exploration Initiative to New York City school students who visit AMNH. NASA has also developed an after-school program to accompany the field trip and provide greater depth of instruction. This program focuses primarily on human exploration and includes a discussion of the space robotics program.

Girl Scouts Exploring in the 21st Century --- Promise Them the Moon and Mars: This program highlights many aspects of lunar exploration, including in-situ resource location through mineralogical mapping of frozen water and lunar minerals and ores; selection of safe landing sites for human and robotic missions; and characterization of lunar environmental hazards. NASA also present robotics connections to 21st century exploration including human-robotic interfaces, robotic-human assist systems, and vehicles for exploration on planetary surfaces. This project uses a train-the-trainer approach in which NASA personnel provide instruction to paid and volunteer Girl Scouts USA staff, who then return to their home areas and provide further training to troop leaders who then present the material to Girl Scouts.

Sports and Exploration: This project is a bilingual, hands-on educational program designed in collaboration with the Houston Dynamo Major League Soccer franchise and the Houston Independent School District, targeting STEM, Health, and Physical Education content in grades 3-5. The program relates national sports fitness standards to the laws of nature through fundamental physics, and emphasizes the message of lifelong health and fitness needed for long-duration space exploration.

Librarian Workshops: This project provides content related to lunar exploration to librarians and after-school providers who use the material in after-school and weekend programs.

Explore! Life Sciences – Health in Space: Managed by NASA Johnson Space Center, the project includes development of modules, for children ages 8 through 13, that stimulate children to think about life in space; the extreme conditions of the space environment (i.e., radiation and microgravity); how these conditions affect the human body; and what NASA researchers are planning to counteract these effects. Information is presented via a variety of methods, including presentation of the modules on an existing Web site for broader access; training of sixty after-school providers at workshops in Mississippi and Alabama; and involvement of the existing ‘Explore!’ community of trained librarians in the use of the new modules.

The Great Light Racer Championship: This competitive educational program is designed to allow middle school and high school students to participate in a plausible lunar exploration scenario – powering a robotic rover in the dark recesses of a permanently shadowed lunar crater – while learning about planetary science, physics, engineering, and exploration. Topics include why we want to reach the permanently shadowed lunar craters and the reasons why this is difficult; possible engineering approaches such as terrain navigation, in situ resources utilization, etc.; and trade-offs such as power beaming between a rover on top of the crater to another at the bottom of a crater. The students design, build, navigate, and race a remotely controlled rover vehicle.

In a May 2008 Gallup Poll, entitled: “Public Opinion Regarding America’s Space Program,” prepared for the Coalition for Space Exploration, one particular section dealt with the “Extent to which the Public Feels America’s Space Program Inspires Young People.” In particular, the poll question was worded as follows: *“To what extent do you believe America’s space program inspires young people to consider an education in science, technology, math, or engineering fields? Would you say the space program inspires these students a great deal, some, very little, or not much at all?”* Results indicated that most (69%) of the adult public surveyed say they believe America’s space program inspires young people to consider an education in science, technology, math, or engineering fields at least to some degree. One in five (21%) believe the program inspires young people a great deal.

ESMD and the Constellation Program agree with this assessment and strongly believe that education is the key to ensuring not only the continuation of NASA’s exploration mission, but also the continuation of our country’s leadership in discovery and innovation across all fields of science. As the United States begins the second century of flight, NASA believes the nation must maintain its commitment to excellence in STEM education to ensure that the next generation of Americans can accept the full measure of their roles and responsibilities in shaping the future.

Appendix C: Constellation Program Budget Development and Acquisition Strategy

Budget Development

The Constellation Program has been underway for 3 years, and thus the budget estimates have a fidelity of 3 years worth of annual evaluation. In the spring of 2006, the Constellation Program developed an unconstrained "bottoms-up" budget estimate for the purposes of establishing a "first cut" understanding of the drivers for costs and schedule from present to the lunar landing phase of the program. This analysis provided the element break-down and the raw data for building a subsequent budget that was realistically constrained by Agency priorities and needs. By the summer of 2006, the program was able to establish the first budget baseline meeting Agency schedule commitments.

Completion of the program's System Requirements Review in late 2006 and the program's System Definition Review in 2008 provided a further level of requirements development that allowed for more refined estimates in the Agency's budget development cycle. Figure C-1 shows a FY07 projection of Constellation NOA by project FY08 – FY13 ($M). Note that the early years of the program are budgetarily constrained by the completion of the Space Shuttle Program. A ramp up to full manufacturing and production capabilities for the Orion and Ares I vehicles can be accomplished after successful transition of many of the Space Shuttle assets and facilities to the Constellation Program after 2010.

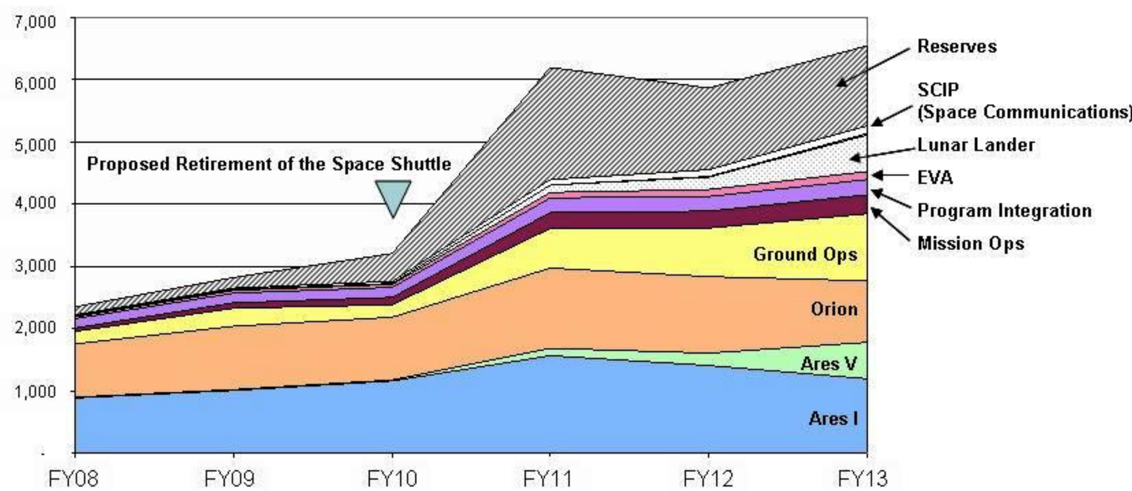


Figure C-1. Constellation near-term budget allocation by project. [21]

Confidence Level

The history of human spaceflight is replete with examples of cost overruns due to confluence of under-funding, insufficient or poorly phased reserves, misunderstood risks and complexities, overly aggressive schedules, and difficulties meeting ambitious technical requirements. The Constellation Program will not be immune to these challenges; therefore, the program is pioneering within NASA the implementation of probabilistic techniques to assess the confidence level expected that the program can achieve given schedule milestones within the budget allocated. Our guidance within the Agency is to maintain a confidence level of 65% that we can meet our schedule commitments within the allocated budget and technical baseline. Program confidence level is calculated incorporating project-level confidence levels, project-level risks, and program-level risks, along with assumptions on dependencies among the risks.[22] The program conducts confidence-level assessments during the budget development process, and refines these during annual budget cycles. This analysis is key to assuring that we maintain our commitments to our stakeholders and have underpinning rationale for dialogue when requirements changes to the baseline are under consideration. While pioneering this technique, the program has learned that we must find efficient ways to incorporate our use of Space Shuttle heritage hardware, facilities, and processes into our estimating tools. In general, we believe these to have a high cost confidence relative to new developments, and the tools in use today are unable to account for this. This is one more area in government where Constellation is leading the way.

Acquisition Strategy

As plans are made for the retirement of the Space Shuttle, NASA is assessing possible synergies to be gained between the contracts and acquisition strategies already in place. The Integrated Acquisition Roadmap Team has been chartered to map all existing and planned Space Shuttle, ISS, and Constellation contracts and to identify opportunities to save costs, including life cycle costs, to use lessons learned and best practices, to address transitions across program phases, to maximize the effective use of both the existing civil service and contractor workforce, and to facilitate strategic competitive opportunities.

Where appropriate, the Constellation Program is using current, proven technology to achieve safer, more reliable and affordable solutions. For example, the Ares I and the Ares V are based on proven systems from the Space Shuttle, Expendable Launch Vehicles, and the Apollo Saturn V Programs, enabling NASA to reduce development costs compared to designing and building an entirely new launch vehicle. This approach maximizes the value of existing facilities, certified parts, production tools, and expertise. Common propulsion elements help reduce operation costs for a more sustainable exploration program. The Constellation Program has entered into sole source production contracts for heritage-based elements; ATK Corporation for the Ares I first stage, and Pratt & Whitney Rocketdyne for the J2-X engine.

Lockheed-Martin was selected as the prime contractor for the Orion development through full and open competition. The production contract for the Ares I upper stage was recently awarded to Boeing Corporation. Boeing also won a separate competition for the Ares I Instrument Unit. The Ares I and V first stage development has been awarded to the ATK Corporation. The Extravehicular Activity Systems prime contract award is planned to be completed in 2008.

The Constellation Program acquisition strategy places an emphasis on the criticality of reducing and controlling life cycle cost in each acquisition phase because NASA plans to produce and fly these vehicles for decades to come. Understanding and managing life cycle cost is pivotal to the overall long-term success and viability of the program.

Figure C-2 shows a projection of the total Constellation Program budget by project through the first human lunar landing in 2020 ($M).

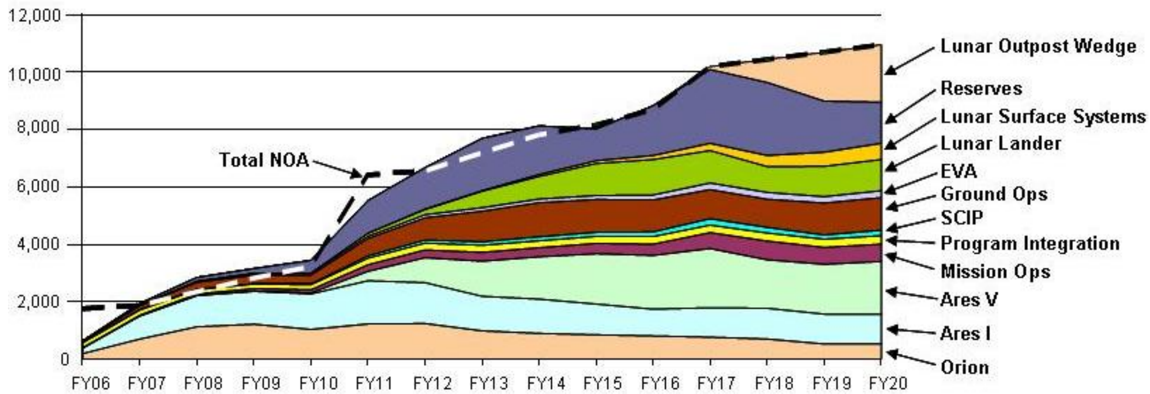


Figure C-2. Constellation long-term budget allocation by project. [21]

Appendix D: Constellation Program Operational Philosophy

It is clear from past experience that the cost burden of Space Shuttle operations cannot be inherited by the Constellation Program if the lunar capability and the eventual Mars capability are to be developed concurrently with the program operations. While the Constellation Program has the advantage of a much simpler system (from a purely engineering standpoint) to operate, this system is based on heritage hardware and its associated operational processes. To that end, the program has designated a Program Operations Engineer to oversee the minimization of operational costs. Several initiatives are underway in support of this effort.

Design for Affordability: Adapting a practice from military and commercial application, a design for affordability effort is underway to identify and ameliorate key drivers to operational costs. Currently, the baseline operational costs are being validated by an independent contractor. This contractor will deconstruct the operational cost estimates by phase of program (production, integration, and mission) and by three additional dimensions: product/platform; workforce, including crew, ground, and mission operators; and ground based infrastructure. This is intended to drive out key cost drivers to define a path and architecture for operational cost reductions, as well as identify the risks and system-level trades necessary to achieve an affordability target.

Contracting Strategies to Reduce Operations Cost: The Program Operations Engineer manages a working group to address current contract strategies for operational cost reduction and recommended improvements. The working group is intended to engage senior procurement, project, and engineering management officials in strategic planning to produce the fundamental culture, process, and content changes achievable through contracting that must be realized to succeed in minimizing operations costs.

Stretch Requirements: The architecture requirements include ‘stretch requirements’ defined as those that enable ground and flight system supportability and reductions in operational life cycle costs. Modeled after the Boeing 777 development, stretch requirements specify a desired outcome believed to simplify operations. For instance, a ‘clean pad’ concept has been specified to challenge designers to minimize services and interfaces required at the launch pad as well as location/access on the vehicle. Each service or umbilical (e.g., cooling) attached to the launch vehicle is thus challenged for relevance or ‘must have’ capability. The Ground Operations Project and Mission Operations Project are focal to managing the stretch requirements; these are incorporated into flight design via negotiation of Interface Requirements Documents with each of the flight projects (Orion, Ares, Altair, and EVA).

‘Con Ops’ Development: Constellation has developed a Concept of Operations (Con Ops) for operation of the program through its mission phases, to drive out operational features that influence hardware, software, and interface requirements. This is a typical best practice in large technical program development. Design reference missions have been developed for ISS missions, lunar sortie missions, lunar outpost missions, and a Mars mission so that operational design drivers are identified early.

Constellation has also initiated similar but perhaps unique Con Ops efforts for targeted processes that can influence life cycle costs. For example, the current practice of quality assurance in the Space Shuttle Program is being benchmarked for efficiency improvements. By developing a Con

Ops for how quality assurance is conducted through the life of the program, a more efficient path to quality assurance is being determined before it is needed for Constellation flight hardware manufacture.

Life Cycle Cost Evaluations: Change evaluations to the program baseline must include an assessment of the life-cycle cost impact of each change to the baseline. Constellation procurements – both ‘end-item’ and ‘award fee’ types – include incentives to reduce life-cycle cost.

Lean Efforts: Lean six-sigma and Kaizen studies were conducted on early developments, such as the Ares 1-X test flight and Orion Flight Test Program. This has proven successful and the program is seeking further opportunities to gain process time reduction and simplification.

The ‘handoff’ between designers and the sustaining engineering and operational communities is being studied for efficiency improvements. Current practice includes overlapping responsibilities and designer involvement in post-design processes. Efforts are underway to identify and minimize this to ultimately reduce costs.

Industry and Experience Advice: The Ground Operations Project conducted feasibility studies under the Broad Area Announcement capability; requesting novel ideas from industry on how to streamline processing, launch, and recovery operations. The concepts are intended to produce ‘cleaner’ techniques and processes in the belief that fewer anomalies are possible with simpler processes. Examples of concepts include new approaches to emergency egress system for the crew, isolation of the launch pad lightening protection system, and alternatives to hypergolic fuel loading to reduce processing time.

NASA also released a Broad Area Announcement regarding the Lunar Lander concept which requested industry approaches to minimizing Design, Development, Test, and Evaluation (DDT&E) and life cycle costs. In the past, NASA has used different approaches to the formation of the initial government-industry design team and transition to a prime contractor for its major development projects. With this Broad Area Announcement, NASA is seeking to identify the most effective option for Lunar Lander development, including assessing the option of maintaining an in-house NASA design team through the Preliminary Design Review and then transferring development responsibility to a prime contractor.

Appendix E: Web Sites with Additional NASA and Constellation Information

Constellation Internet Resources

(http://www.hq.nasa.gov/office/hqlibrary/pathfinders/constellation.htm)

NASA Web sites

For more information about NASA's Constellation Program:
http://www.nasa.gov/constellation

For more information about NASA's Ares launch vehicles:
http://www.nasa.gov/ares

For more information about NASA's Orion Crew Vehicle:
http://www.nasa.gov/orion

For more information about NASA's Altair Lunar Lander:
http://www.nasa.gov/mission_pages/constellation/altair/index.html

For multimedia information about NASA's Constellation Program:
http://www.nasa.gov/mission_pages/constellation/multimedia/index.html

For Constellation fact sheets, animations, and studies sources:
http://www.nasa.gov/mission_pages/constellation/news/index.html

For more information about the Ares V heavy lift launch vehicle and the Altair lunar lander and the roles they will play in returning humans to the Moon by 2020 (presentations from an Exploration Systems Mission Directorate forum held 9/25/08):
http://www.nasa.gov/directorates/esmd/home/lunar_id.html

For more information about the Exploration Systems Architecture Study:
http://www.nasa.gov/mission_pages/constellation/news/ESAS_report.html

For more information on NASA's Exploration missions:
http://www.nasa.gov/mission_pages/exploration/main/index.html
http://www.nasa.gov/topics/moonmars/index.html

For more information on the Shuttle to Constellation transition:
http://www.nasa.gov/mission_pages/transition/home/index.html

For a selection of Constellation Program (and other NASA) videos:
http://www.youtube.com/ReelNASA

For an overview of NASA history and 50th Anniversary celebrations:
http://www.nasa.gov/50th/home/index.html

Constellation Contractors' Web sites

Lockheed Martin. Orion Crew Vehicle:
http://www.lockheedmartin.com/orion

Orbital Sciences Corporation. Crew Exploration Vehicle:
http://www.orbital.com/AdvancedSpace/CEV/index.html

NASA Education Information Web sites
(For some of the programs mentioned in Section 4 of this white paper)

Space Grant Internships/Senior Design Projects: http://education.ksc.nasa.gov/ESMDSpaceGrant/

University Student Launch Initiative:
http://education.nasa.gov/edprograms/descriptions/University_Student_Launch_Initiative.html

Spaceward Bound:
http://quest.nasa.gov/projects/spacewardbound/

Systems Engineering Educational Discovery:
http://www.tsgc.utexas.edu/workshop/agenda.html

ESMD Senior Design Course:
http://www.nasa.gov/audience/forstudents/postsecondary/programs/ESMD_Space_Grant_Faculty_Project.html

Engineering Design Challenge: Lunar Plant Growth Chamber:
http://www.nasa.gov/audience/foreducators/plantgrowth/home/index.html

21st Century Explorer:
http://education.jsc.nasa.gov/explorers/

High School Mathematics Modules:
http://education.ti.com/educationportal/activityexchange/activity_list.do?cid=us (*search on "NASA" to find modules)*

Space Faring: The Radiation Challenge:
http://spacefaringradiation.org/

Lunar Nautics:
www.nasa.gov/education/lunarnautics

NASA Fit Explorer:
http://www.nasa.gov/audience/foreducators/fitexplorer/home/index.html

The Space Exploration AP Project:
http://education.ti.com/educationportal/activityexchange/activity_list.do?cid=us
(search on "NASA" to find practice problems)

The USA TODAY Collaboration:
http://www.usatoday.com/educate/NASA/index.htm

A Field Trip to the Moon:
http://education.amnh.org/school_groups/offering.php?id=85

Librarian Workshops:
http://www.lpi.usra.edu/education/explore/LRO/

Explore! Life Sciences – Health in Space:
http://www.lpi.usra.edu/education/explore/space_health/

Appendix F: A Visual Overview of Recent Constellation Progress (Nov/Dec 2008)

1. Preparations for the Ares 1-X launch from Kennedy Space Center in spring 2009:

The Ares Upper Stage Simulator Segments were shipped from the NASA Marshall Space Flight Center to Port Canaveral, Florida, and transported past Launch Pad 39 to the VAB at Kennedy Space Center for final assembly and launch preparation.

The Ares 1-X Forward Skirt Extension segment completed structural assembly and painting at Major Tool Machine in Indianapolis, Indiana (a subcontractor to ATK in Promontory, Utah). Developmental Flight Instrumentation installation was completed and the unit was shipped to Kennedy Space Center. A thermal cycle test and 8-foot-drop test were performed on the Forward Skirt Extension qualification unit.

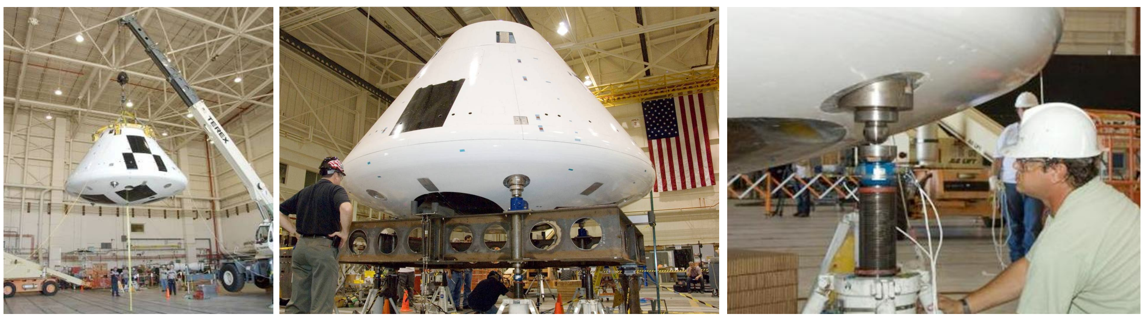
The Ares 1-X Crew Module and Launch Escape System (LAS) Simulators completed final assembly at Marshall Space Flight Center and are shown above with their initial coat of primer paint. The Crew Module shipping platform (above right) was also completed.

A 70-foot shipping and rotation trailer for the LAS was completed. A load test of the trailer cradle was performed (above left) and the LAS-base simulator was used for a fit-check (right, with final white paint).

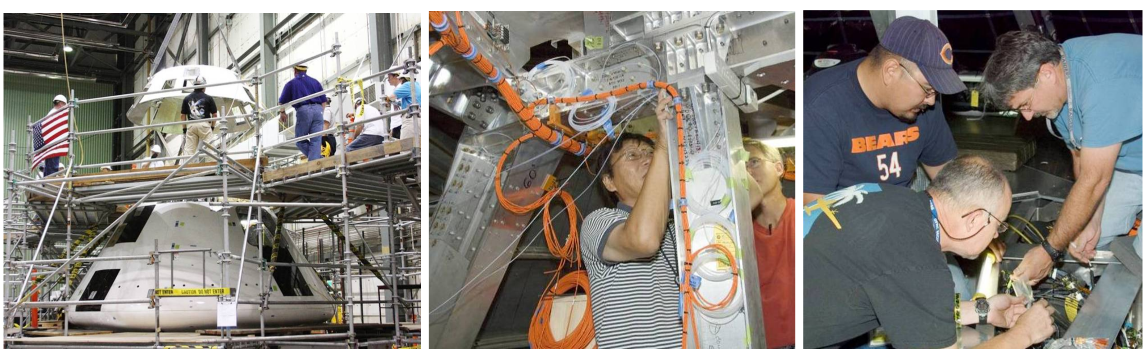
The Crew Module and LAS-base simulators for Ares 1-X were successfully stacked (above left) for a mate test and match drilling. This hardware will be shipped to Kennedy Space Center in early January. Ares 1-X solid rocket motor segments are cast and cured at the ATK facility (above center) and prepared for X-ray inspection (right).

2. Preparations for the PA-1 test flight from the White Sands Missile Range in New Mexico in spring 2009:

The PA-1 Crew Module was delivered to the NASA Dryden Flight Research Center for flight test preparations and integration and checkout of flight electronics.

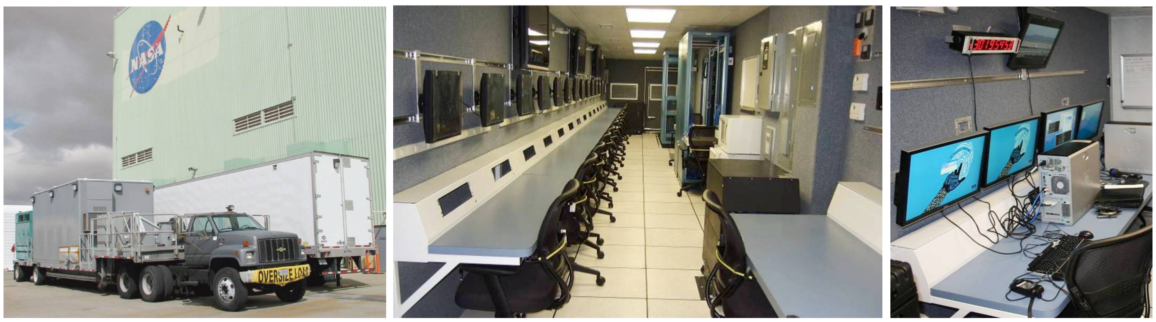


An initial weight and balance test was conducted on the PA-1 Crew Module (above).



Following Crew Module installation in the access stands, Developmental Flight Instrumentation, and wire harnesses associated with flight sensors were installed.

Parachutes were packed and fitted into the upper portion for the Crew Module (above left and center), along with explosive mortars (right) for deploying the drogue and pilot parachutes during the PA-1 flight.



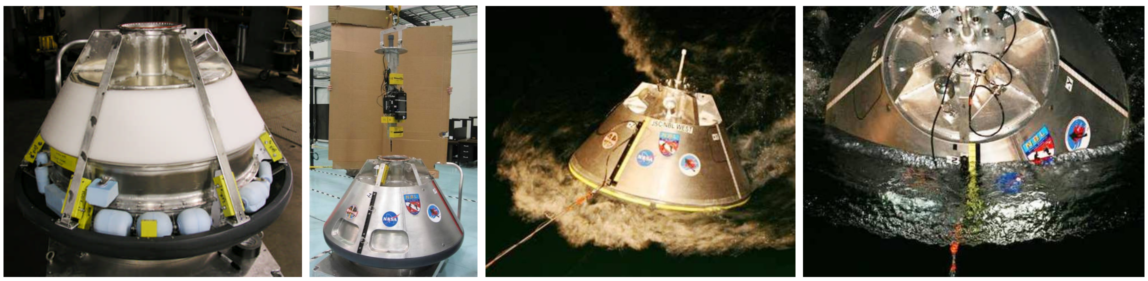
The Vehicle Integration Van (gray trailer above left) and Mobile Operations Facility (white trailer) completed preliminary outfitting. The Mobile Operations Facility (interior shown above center and right) will serve as a portable test and checkout facility and launch control center for all of the Pad Abort and Ascent Abort test flights.

The LAS abort motor (above left) was transported to the ATK test site in Utah for its first full-scale system test firing (right) in late November. The test was a complete success.

The LAS abort motor manifold assembly during manufacturing (far left). The LAS nose cap was completed and shipped to Dryden Flight Research Center in December. The photo (left) shows the nose cap integrated to the instrumented nose cone section.

3. Other recent Constellation activities:

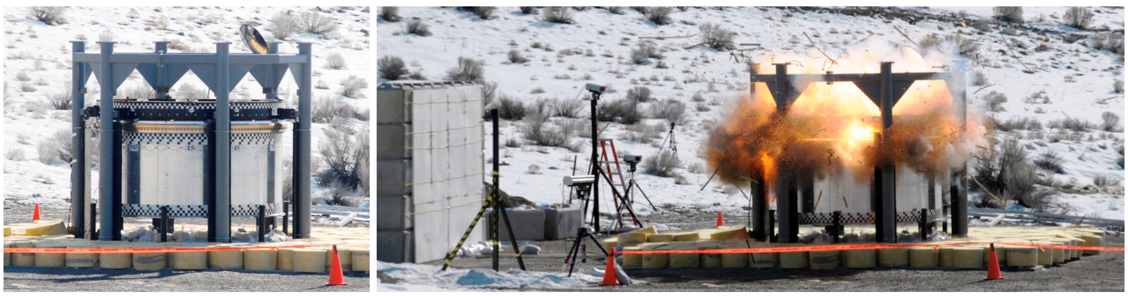
A Service Module solar array deployment test (above left and center) was conducted at the NASA Glenn Research Center in Cleveland, Ohio. Construction of the Ares J-2X Engine Test Stand (above right) is underway at the NASA Stennis Space Center in Mississippi.



A quarter-scale model of the Crew Module (above) recently completed water towing tests at NASA Johnson Space Center. The Crew Module model was also tested for water stability and self-orientation during water landing.

Left: The Ares I-X test flight Launch Abort System is assembled at the NASA Langley Research Center. Right: The Ares I-X First Stage Avionics Module assembly at Lockheed Martin Denver.

Transfer of the Launch Abort System model from Langley to the Kennedy Space Center was completed in early 2009.



A full-scale explosive separation test of the forward skirt extension for the Ares I-X flight test was successfully conducted in Promontory, Utah on January 29, 2009.

Left: Launch pad modifications for Orion/Ares flights at the Kennedy Space Center include installation of three 600-ft lightning protection towers to accommodate the taller height of the Ares I rocket compared to the Space Shuttle. Right: The prototype Lunar Electric Rover during desert testing.

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